LOOKIE HERE! DESIGNING INTERVENTIONAL USER INTERFACES FOR CONDITIONAL SELF-DRIVING VEHICLES

A Dissertation
Presented to
The Academic Faculty

by

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"LOOKIE HERE!" DESIGNING DIRECTIONAL USER INDICATORS FOR CONDITIONAL SELF-DRIVING VEHICLES

Approved by:

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LIST OF SYMBOLS AND ABBREVIATIONS

UI	User Interface
AV	Autonomous Vehicle
SAE	Society of Automotive Engineers
TOR	Take Over Request
POI	Point of Interest
FOV	Field of View
ANOVA	Analysis of Variance
SUS	System Usability Scale
TLX	Task Load Index

SUMMARY

In this paper I investigated whether providing directional alerts to a user's active screen can augment their ability to regain situational awareness when traveling in a conditional autonomous (Level 3) vehicle. A user study (N=15) was conducted in the lab environment with a driving simulator, where users were distracted by playing a game on a mobile device. A non-directional alert was compared to two separate directional alerts: the central user interface (UI) and the peripheral UI. One located at the center, and one located at the periphery of the participant's vision while they were focused on the mobile device screen, to understand whether direction data can assist the user. Although there were no significant differences in reaction times, participants perceived themselves performing better when provided with directional alerts. Our findings imply that directional user interfaces have the potential to reduce overall cognitive load and lead to better user experiences for passengers of self-driving vehicles.

CHAPTER 1. INTRODUCTION

With the introduction of autonomous vehicles (AV) it is becoming increasingly important to explore different user interaction possibilities as people in the cabin are released from dynamic driving tasks (DDT). The ubiquity of computing systems, and the evolution of the artificial intelligence industry have generated new opportunities for human automation interaction design [23]. The importance of creating adaptive interactive systems that cover the full spectrum of human attention to provide a more engaging user experience has been previously documented by Bakker and Niemantsverdriet [2]. It will soon become essential to empower users to perform multiple tasks at different attention levels for future user interfaces to be able to provide a more comprehensive user experience.

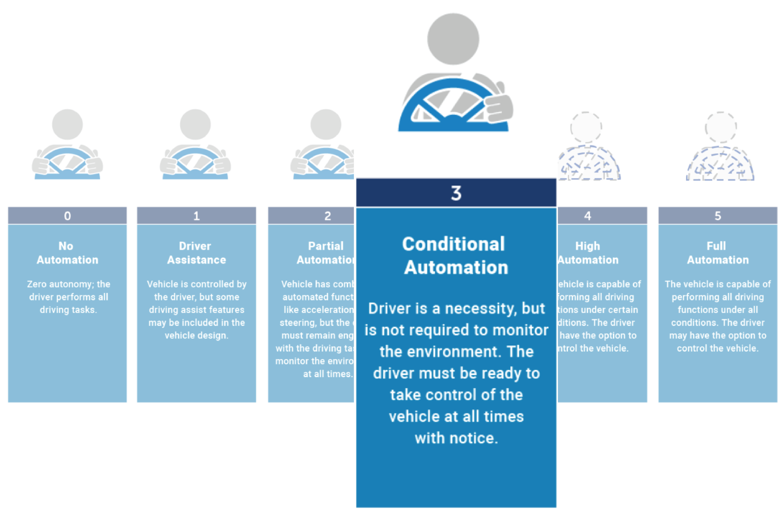


Figure 1 - SAE Levels of Automation

As a critical milestone in the self-driving evolution of most automotive OEMs, level 3 self-driving is defined by the SAE (Society of Automotive Engineers) as conditional level of automation where driver attention is a necessity and is required to monitor the environment [26]. However prior studies have implied that once people start trusting the autonomous system, they are more likely to be engaged in activities such as checking emails or watching videos that divert their attention for extended periods of time [10]. Such behavior would make it extremely difficult for them to react effectively within the short duration required to prevent an accident. One of the design challenges under this condition (level 3 or lower) is to improve the reaction times and situation awareness of people in the AV when potential hazards are detected by the automation system. Once the system reaches its limits, i.e. it is no longer able to handle a hazardous situation, it submits a Take Over Request (TOR) to the driver. A Take Over Request is a protocol wherein the automated vehicle requires the rider to assume manual control of the vehicle to handle a situation. Current TOR protocols typically focus on notifying the driver about the possibility of a hazardous situation and still require the driver to take control of the vehicle in a traditional manner, i.e., with their eyes on the road, arms at the steering wheel and foot ready to press the brake pedal [4,7,16,20,21,25]. Other studies have highlighted how using multimodal channels to communicate TORs have led to reductions in user reaction times during driver takeover [20,21,25]. However, there is an opportunity to further research the benefits of providing visual directional information to improve human response times during takeover, especially when people are immersed in portable devices or other screen-based tasks [7,15,25]. The objective of this research was to investigate whether providing directional indications on the user's active mobile devices could improve their reaction times in identifying a potential hazard on the road.

The method proposed in this paper is inspired by the gaming industry. Different genres such as first-person shooters (e.g. Call of Duty) and action role-playing games (e.g. Mass Effect) have taken advantage of directional indicators in different 3D scenarios to communicate a threat or Point of Interest (POI) located outside the gamer's Field of View (FOV) using different abstract symbols such as arrows, avatar, mini-maps or other visualizations [9,14]. These techniques have been found to be extremely effective in multiplayer gaming communication to assist players in immediately identifying the direction the hazard is coming from. One key difference in implementation, however, lies within the next steps a user needs to perform upon receiving the alert. Within the gaming environment, users do no need to change their orientation, they simple move their cursor towards the POI. However, in a driving scenario, the user must reorient themselves to look outside to be able to locate the POI. This interaction gestalt prompted the exploration of solutions that went beyond the limits of the screen of a non-directional interface.

This research focused on implementing similar indicators contextually, to assist a driver during the process of a Take-Over-Request (TOR). To this end, a user study was conducted with fifteen participants to compare the effectiveness of different methods for providing directional indications to assist users in gaining situational awareness in a short time frame to facilitate a faster response rate. Additionally, this research explored the intuitive nature of such messages in communicating an oncoming point of interest (POI) and how users react upon receiving them.

CHAPTER 2. BACKGROUND

Autonomous vehicles (AV)s have been a concept fantasized in sci-fi for years, however, recent progress in the automotive industry are turning them into accessible products and services [22]. Once drivers transfer the primary task of driving to their vehicle, driving a car will have less to do with expressing one's identity and more to do with humans inhabiting mobile spaces [12]. A key concern for this industry has been to try and understand how AVs can reduce automobile-related accidents and improve everyday commuting experiences [8]. Lessons learned by companies such as Tesla, Waymo, and Uber in creating and testing their self-driving cars on public roads indicates that this emerging concern needs to be further investigated from a user's perspective by the HCI and design research community [22].

2.1 Attention Distribution and Takeover Challenges in Level 3 AV

In level 3 conditional automation, the driver must be ready to take control of the vehicle at all times when alerted to do so [18]. As vehicles and travel are unique experiences for each individual rider, it is difficult to ascertain whether riders want increased control over their vehicles, or whether they are willing to give up control over to a system they trust to handle the task better [3]. This is an important consideration in a highly automated environment, which might require different mental resources for switching between several tasks than those demanded by manual driving, as riders will now be required to monitor multiple operations of the car without active control over them [6]. Studies have found that drivers not only engage in a wider range of non-driving tasks under autonomous conditions, but also increase interaction rates and frequency of occurrence between these tasks [13]. The same study found that once the drivers trusted the system, they would more readily engage in activities considered hazardous in non-autonomous situations [13]. For some, the removal of the driving task is seen primarily as an opportunity to engage in a more intimate social dynamic with friends, such as sitting around a table and facing one another, while others prefer facing the road and only turn their heads to communicate [10]. The above findings would imply that people are likely to be engaged in activities that divert their attention for longer periods of time, making it difficult for them to react within the short duration at their disposal during an accident.

2.2 Interventional User Interfaces across Multiple Devices

Interventional user interfaces are regarded as a new interaction paradigm for various automated systems such as AVs [27]. Meanwhile, the inside of the car can be treated as part of a ubiquitous computing ecosystem consisting of multiple devices including the car, mobile phones, and wearable technology, each vying for the user's attention [22]. As riders operate within autonomous cars, there is a need for adaptive user interfaces that the riders can intuitively engage with based on the driver's context and immediate cognitive capabilities. While this space has not received much attention from the human-automation interaction community[11], it has been explored in the field of ubiquitous computing and interaction design of consumer devices [1,2,11,24]. Bakker and Niemantsverdriet viewed the human attention span with regard to interaction design as a continuum, with mental resources being distributed to multiple tasks based upon priority and time of day [2]. There has been a need to seamlessly fit technologies into everyday routines across multiple devices. For example, integrating sensors and a mobile app into the lighting ecosystem enables users to interact with the system casually, such as using gestures to turn the lights on, to more focused interactions such as picking a particular hue of light via the app [2]. Other studies have also illustrated an interesting aspect of user adaptation to interaction difficulty: allowing users to achieve their goals at a range of levels of engagement demonstrated that users do change their engagement depending on the difficulty of the task at hand [24]. This would imply that, depending on the user's mindset and their context, computing technology may at one moment be interacted with through focused interactions, in the next moment through peripheral interaction, and in yet another case through implicit interaction [2]. Empowering users to perform multiple tasks at different attention levels will lead to a more seamless and enhanced user experience [2].

This study hypothesized that one viable option would be to present alerts to users on the active screen of their mobile device to prompt faster reactions. In this instance, an active screen is defined as the mobile screen on which a user's attention is focused. Politis et al. witnessed better takeover performance from participants when TORs were delivered to the active device [25]. Building on aforementioned work, we propose further development of directional user interfaces, i.e., alerts that don't just inform the user of an oncoming POI but also provide its location relative to the user's orientation.

CHAPTER 3. METHOD AND PROCESS

By adhering to research through design, we conceptualized two directional alerts: one that would appear in the direct area of attention for the user, called the central user interface, and another that would appear in the periphery of the user's attention called the peripheral user interface. The central interface was a digital user interface designed to interrupt any task the user was performing on their active device and present the alert on the active screen. The peripheral interface was a physical interface that rested on the edge of the mobile device, and when engaged, would transform mechanically to communicate direction and distance of an incoming POI.

Both solutions were developed using the Wizard of Oz technique to be ready for user testing in a low-fidelity environment. The purpose of the interfaces was to alert the user to an incoming point of interest while providing abstract distance and directional information to augment the user's ability to regain situational awareness.

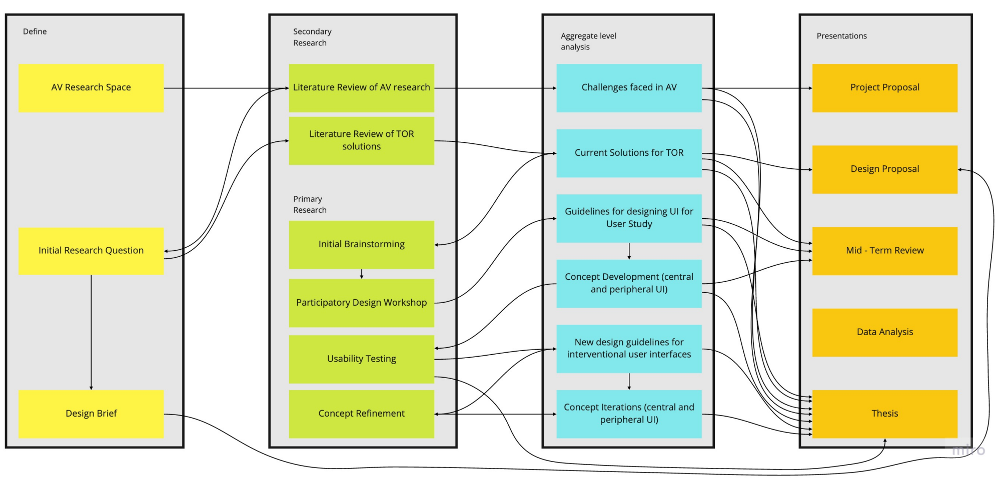


Figure 2 - Research Framework adopted for this thesis

Presented above (Figure 2) is the framework I followed throughout this research endeavor. The arrows within the framework indicate how one set of methods informed the next steps within my process. Inspired by research through design, this framework encouraged the researcher to build, evaluate and iterate on ideas every step of the way. Starting from initial sketch concepts which were evaluated and refined in a participatory design workshop, right through to a usability study with high fidelity, low resolution prototypes that provided me with insights and final design suggestions.

3.1 Participatory Design Workshop

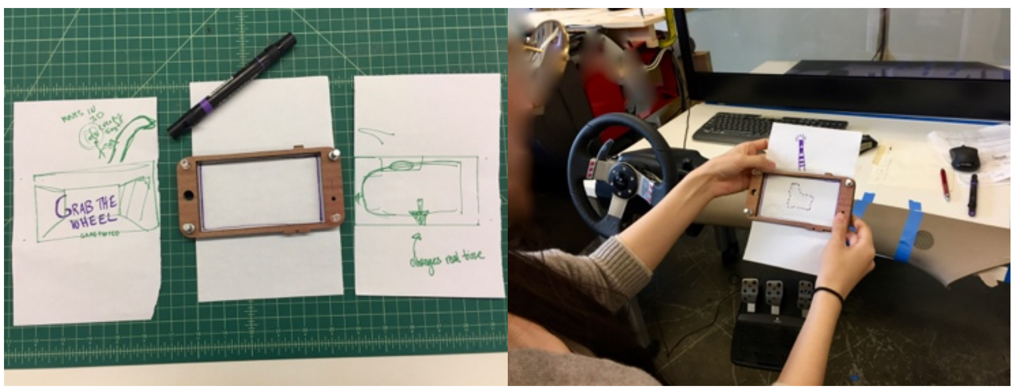


Figure 3 - (L) User Interface recommendations (R) Design workshop in progress

A participatory design session was organized to collect early stage concepts for the directional interfaces and feedback on the user study design from designers (the participants) within the Human-Machine Interface Lab at Georgia Tech. Four participants with more than three years of design experience were invited to a participatory design workshop. Each participant was individually seated in front of a low fidelity simulator environment and was introduced to the basic user scenario of a passenger distracted by their mobile device during a journey in an autonomous vehicle. The participants were presented with low fidelity mobile phone prototypes which included a blank sheet of paper that depicted the real estate or area within which their attention would be focused. Once briefed through the driving scenario, the participants were presented with each of our concepts and asked to interpret how they felt the alert would manifest itself on the interface through word, gestures, or sketches. This visual interpretation was documented by requesting each participant to sketch on the piece of paper provided and think aloud as they worked through how each solution might operate for a given use case.

The participatory design workshop provided several insights, and recommendations that informed key aspects of the design of the user interface alerts, as well as the user study created to evaluate them.

- The researcher should articulate the autonomous driving experience with an example at the very beginning of the user study. This helps reduce confusion regarding intended functionality of the solution.

- Designers responded well to the **compass-like** forms.

- Lighting condition may be a critical issue in the user study.

- Once the peripheral interface provides a direction, suggestions were made for a **secondary interaction** (like a laser pointer) that could highlight a part of the windshield for users to know where to look.

- Most designers responded well to **relative** directional data relative to their orientation over absolute, especially in highly autonomous conditions.

However, issues were communicated regarding when users have to look behind them.

- Information should be displayed to reinsure users that their progress on the active device has not been lost.

- Any additional info, may force users to spend more time on the display than outside

- Throughout the study, feedback received from participants reinforced the important of the interaction gestalt mentioned at the beginning of this research; the goal of the alert was to ensure users reorient their eyes to **street view**

During high immersion, such as playing a video game, it may be difficult to notice movement in the periphery. Hence, the peripheral solution would have to be extremely obvious, for example, physical motion or lights.

3.2 Concept Development

Based upon these insights, we proceeded to refine and finalize the two directional alerts that we would evaluate in our user study.

We originally considered interrupting tasks for both alerts and focusing on the location of the alert itself, as this would keep the variable of interruption consistent within the user study. However, we believed that it was more important to explore how the directional alert could be provided with or without interrupting the riders active task. This subsequently led to the design of the two interfaces: one at the center of the user's attention and one at the periphery.

3.2.1 Central User Interface

The purpose of the central user interface is to communicate a POI alert to the user in the direct area of their visual attention. It is designed to interrupt the active task a user is performing on their mobile device and update the screen with a user interface that displays the directional alert. The main objective of this solution is to grab the user's attention as quickly as possible. Hence, the solution was designed to appear directly on the mobile interface where the AV control system estimated the user's attention is currently focused and alert them of an incoming Point of Interest.

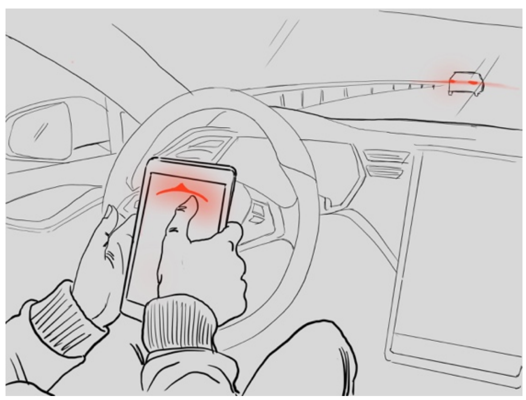


Figure 4 - Central UI Concept

3.2.2 Peripheral User Interface

The main objective of a peripheral solution is to assist the user in regaining situational awareness without interrupting their active task, it achieves this by communicating a POI alert to the user in the **periphery** of the user's attention. This solution is designed to identify whether providing alerts at the periphery, i.e. **without interrupting** the active task the user was performing, will produce a similar or faster reaction with regard to regaining situational awareness. The main objective of such a solution is to grab the user's attention without interrupting their active task, as this gives the user the autonomy to resume their active task before reacting to the POI. Hence, this alert would immediately appear on the periphery of the mobile device where the AV control system estimated the user's attention is currently focused and alert them of an incoming Point of Interest.

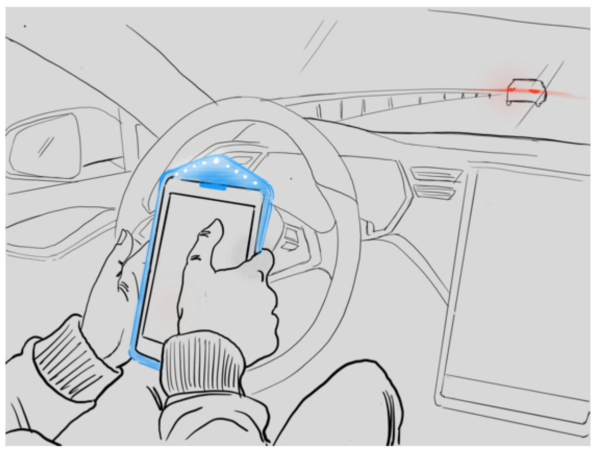


Figure 5 - Peripheral UI Concept

3.3 Prototype Development

The central user interface (Figure 4, Left) was designed in Adobe Illustrator and After Effects. The interface, as pictured in the diagram below, consists of an arrow with a ring for providing spatial reference to a user, similar to a compass. When engaged, the arrow would move to highlight the direction in which the POI was located, as well as update its angle to match the direction in real time. The designed animations and motion graphics were exported in MPEG format to be used in the user study. As this alert was to interrupt the user's active task, the researcher chose to use a custom-built game, Turtle

Survival, as the screen task (the secondary task for "distraction") in the user study. This ~~it~~ provided researchers with maximum freedom to control the simulation, while keeping study participants. The alert would engage in response to a predetermined timer that would launch every time the application was opened. The timer event was created so that the researcher could modify and update when the alert would engage based upon the respective simulation. We considered a button press to engage the alerts. However, we felt that a pre-timed event manually coded into the game would provide more consistency in terms of when the alerts were engaged and leave less room for error (e.g. if researcher mistimed the button-press).

Figure 6 - (L) Peripheral UI Prototype mounted on the back of an iPad, (R) Central UI Prototype

The peripheral user interface (Figure 4, Right) took the form of a physical arrow that would be attached to the back of the mobile device. This prototype would be hidden from sight in the back of the mobile device, until triggered to engage, at which point it would present itself on the relevant boundary of the mobile device. The user interface of the alert was designed using physical prototyping methods. To determine its temporality, this research took inspiration from findings published which highlighted how mechanical motion caught a user's attention faster than traditional change of states, such as color or brightness, caused by ambient lighting [16]. After determining the desired motion, the mechanical and electrical structure that would engage the mechanism was engineered. In this instance, a rack and pinion mechanism would work in sync with a rotational motion on the compass itself to attract the user's attention. The whole system was designed on the open source Arduino platform. All non-electrical parts of the prototype were laser cut from chipboard except the rack and pinion mechanisms, which were cut from acrylic. The parts were designed and assembled using the open-source DIY platform Paper Mech's rack and pinion design as reference [19]. Modifications were made to allow the prototype to function as a peripheral on the mobile device used in the user study. The high torque servo (Sun Founder Metal Gear RC Servo) was used to support the extra weight of the micro-servo and physical arrow. The physical arrow itself consisted of a laser cut base upon which a linear layer of Adafruit's Neopixels was glued to provide lighting that would match that of the digital prototype [28]. The arrow was finally covered with a sheet of mylar to diffuse the light across the entire form and make it feel like a coherent form. During the user study, the peripheral prototype was mounted on the mobile device.

3.4 User Study

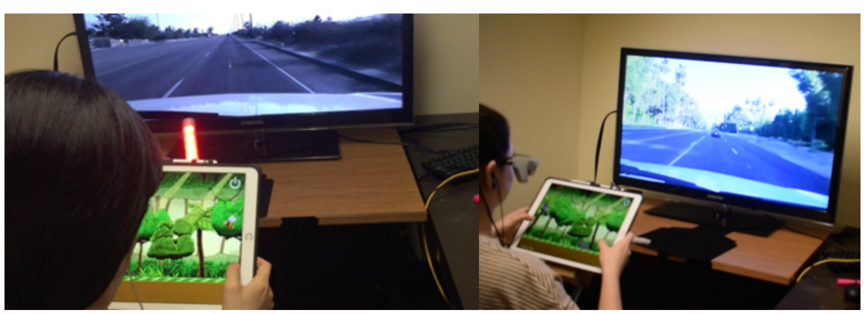


Figure 7 - Simulation setup with the participant involved in secondary task

In order to evaluate the impact of each prototype, a user study was conducted in Sonification driving simulation lab. Both prototypes were compared with a non-directional user interface by collecting quantitative data on reaction times and qualitative data on user preferences in a driving simulator. In this instance, a non-directional user interface (Figure 6), was used as the baseline and defined as a conventional interface which simply provided an alert for an oncoming POI with no additional directional information.

Figure 8 - Non-directional User Interface

The study employed a 2x3 repeated measures within subject's factorial design, where the effect of 3 types of alerts' UI, namely conventional, central, and peripheral, were tested with the participants across two different time instances, 30 seconds and 120 seconds, after the beginning of each round of testing. The study operated under the hypothesis that time spent on secondary task was directly proportional to immersion. There was a total of six rounds of testing per subject. During each round, subjects' reaction data and behaviors were collected through eye tracking, observations and video recordings. The data was then run through a 2x3 repeated measures ANOVA (Analysis of Variance) for further analysis.

3.4.1 Driving Simulator Setup

The driving simulation setup consisted of a high-definition television and foot pedals. The foot pedal was presented only to serve as dummy devices to reinforce the sense of sitting inside a vehicle. Participants were not required to interact with the simulation at all. During an active session, the television played first person view footage of a vehicle navigating through different driving scenarios. Video cameras were setup to record an over-the-shoulder view of participants while they were seated in the simulator environment. Additionally, participants were donned Tobii Glasses to collect eye tracking data during each simulation. The simulations were primarily dash cam footage of cars completing road trips that the researchers found via YouTube.

This study employed a factorial design where the three types of alerts (central, peripheral, non-directional) were presented to the participants in two different time instances of short immersion and long immersion. Three rounds lasted no more than 37 seconds, while the other three lasted a maximum of 127 seconds each.

Table 1 - Examples of POI tested in simulation across immersion times for 3 different alerts

Points of Interest	**30 secs (short immersion)**	**120 secs (long immersion)**
Central	Tornado	Fallen Tree
Peripheral	Lightning	Burning Car
Non-directional	Ball	Horse

3.4.2 *Engaging the prototypes*

Using Apple's XCode platform, the central UI prototype was integrated into the game. And with Arduino communication, the peripheral prototype was integrated into the game as well. A timer event was introduced into the source code of the game with the help of one of the game's developers. This event enabled the researcher to introduce the alert after a certain delay to interrupt the game at a predetermined time. During the user study, the researcher would update the delay in the source code of the game to match the time at which the POI would appear in the simulation. In the central UI, the alert would take two seconds to fully appear on the screen of the mobile device. This delay was intentionally introduced by the researchers to account for the peripheral system response's time including the rack and pinion mechanism and the micro servo motor to be fully engaged.

3.4.3 *Testing Procedure*

After completing the consent forms, participants were introduced to the simulator, Tobii Glasses, and the mobile game they would be required to play as the secondary task. The test started with a warm-up session instructing the participant about how each alert (non-directional, peripheral, and central) worked to communicate a Point of Interest (POI) in the video simulation, as well as familiarizing them with how they are to callout the Point of Interest when they recognize it. They were also familiarized with the mobile device (iPad 12 inch) and the video game controls at this stage. They were also instrumented with Tobii eye tracker equipment to track their gaze. After the warm-up session, the user study was initiated. It consisted of six rounds of testing. In each round, participants were taken through a road trip in an autonomous vehicle. During the trip, they were instructed to perform a secondary task, i.e., playing a mobile game until prompted otherwise. Participants were requested to bring their own headphones or earphones and wear them during the process of the simulation to reduce audio inputs they received. Alerts were sent to the mobile device at a predetermined interval of either 30 or 120 seconds during each simulation. When alerted, participants were required to look up and call out the POI on the screen as soon as they recognized it. Each simulation would end as soon as the POI left the screen. At the end of each round, there was a two-minute break during which participants were asked to identify the POI they had seen in the previous session and locate it on the screen by drawing the POI on a sheet of paper. The sheet of paper contained the frame of the screen of the low fidelity simulator to act as a reference.

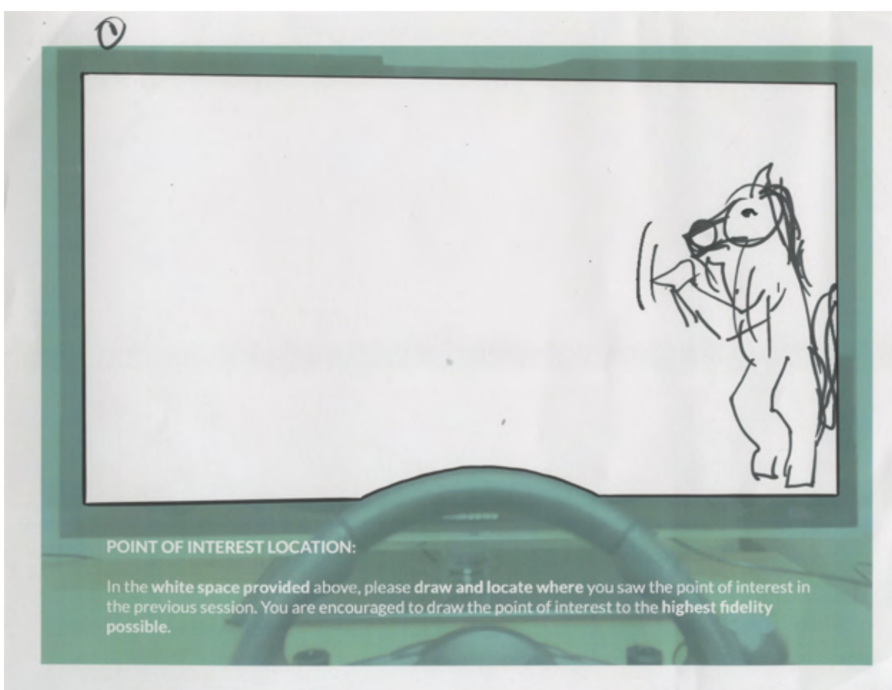


Figure 9 - A sample of the sketch data collected from the participant about POI located in the previous test

Upon completion of all scenarios, participants were asked to complete post study surveys based on SUS (System Usability Scale) and NASA's TLX (Task Load Index) questionnaires and answer a series of open-ended questions. Finally, they were asked to sketch ideas they might have for improving both central and peripheral prototypes, or alternatively, writing them in the form of notes/comments.

CHAPTER 4. RESULTS

During the user study, the researchers collected both qualitative and quantitative data to attempt to answer the questions raised at the beginning of this research. Quantitatively, the researchers collected gaze data via Tobii Eye Trackers and reaction times by recording the callouts of each specific user via video recordings. Between simulations, participants' recollection of where they saw the dynamic POI first appear on screen was gathered by asking users to sketch it out on a piece of paper with a border of the TV screen for reference. After completion of the study, participants were asked to fill out SUS scores for the central and peripheral prototypes.

Qualitatively, users were interviewed upon completion of the post user study survey regarding their impressions on both focus and peripheral prototypes, as well as which alert amongst the three interfaces tested, they preferred the most. Participants were also encouraged to sketch out any suggestions in terms of both form and function they may have for improving the central and peripheral prototypes respectively.

TLX was used to evaluate the overall user study design, it will be stated that the authors are currently studying the TLX scores and are working towards reporting them in a different publication that is focused on designing low fidelity simulations for user testing driving scenarios. The Sketch data collected is currently being reviewed by the authors and was not presented in this paper as it did not directly engage the research question.

4.1 Video Callout Data

During each round of testing, video was recorded of participants calling out POI during each round of testing. A total of 90 videos were collected of which 10 instances were removed either due to video recording error, alert engaging early, or no reaction from participant. This resulted in a total of 80 videos across participants which exported individually. Reaction times were calculated based on the difference between the moment the alerts engage to the time took participants to callout the POI. Once reaction times were calculated, a 2x3 factorial within subjects repeated measures ANOVA was conducted using IBM's SPSS statistical analysis toolkit. The means and standard deviations for each of the six groups have been presented below, as well as a graph highlighting the interaction between modalities and immersion conditions.

Table 2 - Means and standard deviations of reaction times for all 6 groups tested within subjects. Traditional (Non-Directional UI), Digital (Central UI), and Physical (Peripheral UI)

Descriptive Statistics

	Mean	Std. Deviation	N
30sec_traditional (in secs)	1.944	1.1370	9
30sec_digital (in secs)	1.800	.5074	9
30sec_physical (in secs)	1.344	.4953	9
2min_traditional (in secs)	1.756	.3504	9
2min_digital (in secs)	1.733	.2179	9
2min_physical (in secs)	2.756	.8647	9

Profile Plots

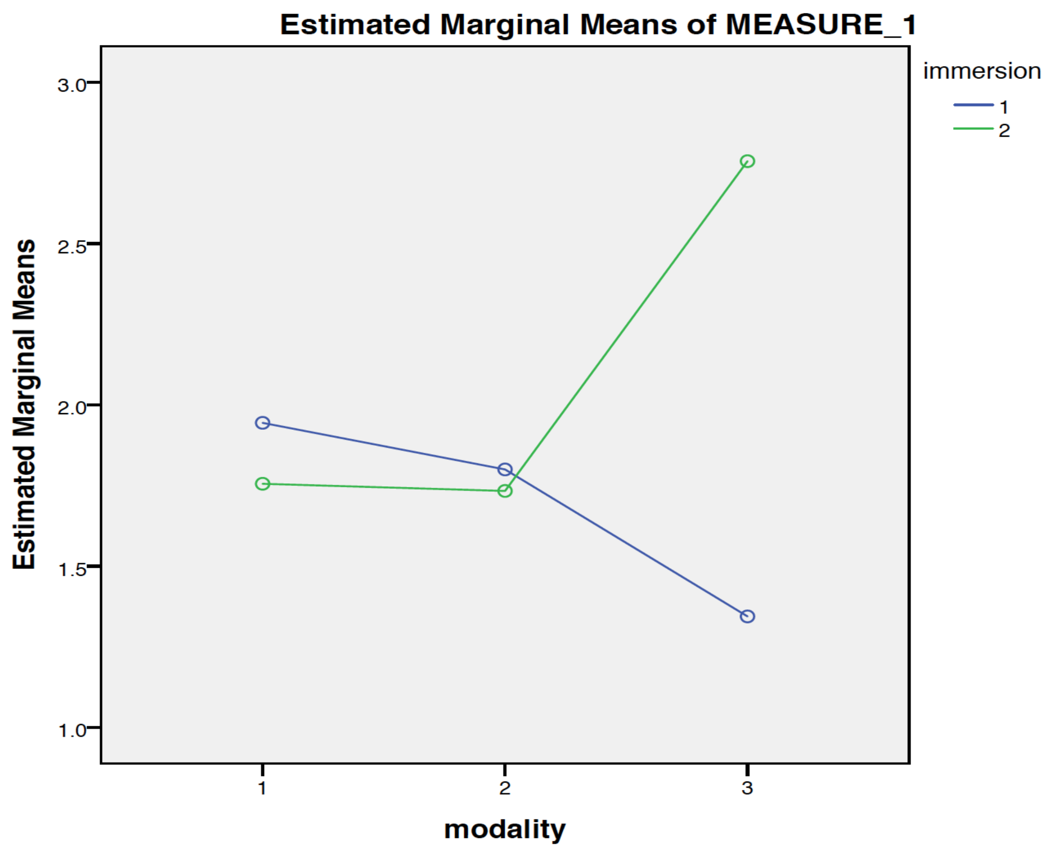


Figure 10 - Graph highlighting interactions between immersion conditions A (30 sec) and B (2mins) across modalities 1 (non-directional), 2 (central), and 3 (peripheral) – need update the diagram: immersion 1, 2 -> immersion conditions A, B. modality 1, 2, 3 -> no

The analysis revealed that the main effect for immersion was marginally significant at $p = 0.054$. The main effect of modality was not significant at $p = 0.448$. However, the interaction between immersion and modality was significant at $p = 0.015$. This may have occurred due to a significant difference between modalities in one of the two immersion conditions. This difference was also observed in the graph shown above. The analysis demonstrated a huge difference in Modality 3 (peripheral) between 30 second and 2-minute immersion lengths. This would imply that the peripheral interface was not very useful once participants were immersed in the secondary task for a longer period of time but may be good for short immersion task switching conditions. Compared with the other two, the central interface does not show significant difference in reaction times across different immersions.

4.2 Eye Tracking

Participants who wore eyeglasses had to be excluded as the eye tracker could not work with spectacles. Eye tracking data was successfully collected for 10 of 15 participants across all six simulations using Tobii Glasses. Of the 60 samples recorded, data loss was experienced due to tracker experiencing technical difficulties tracking a participant's eyes while their head was in motion. The Tobii eye trackers (v1) we possess are technically limited in their ability to capture consistent eye movements to be able to track reaction times. Although they claim to be mobile, they were designed for participants to evaluate static user interfaces on a website without too much head movement. This resulted in an inconsistent dataset of 28 samples of eye tracking data. Due to these reasons, a decision was made to not measure reaction times using eye movement. However, within the 28 samples collected, we observed consistent eye movement patterns between participants which we believe was worth reporting, as we feel it is an interesting topic to explore in future studies. Upon viewing the gaze movements of each participant across simulations both individually and cumulatively, several patterns started to emerge. Due to the small size of valid samples, eye tracking data was used as supplementary data to support user behavior observed by the researchers rather than as critical data in this paper.

Figure 11 - Eye-tracking movement pattern from data sample

4.3 SUS Analysis and Participant Impressions

At the end of the user study participants were asked to score the central and peripheral prototypes on a SUS scale. SUS, usability, and learnability scores were calculated for each participant and mean values have been reported here. Once collected, the researchers reviewed videos of participants' reactions for each prototype to understand why the central and peripheral prototypes received their respective scores.

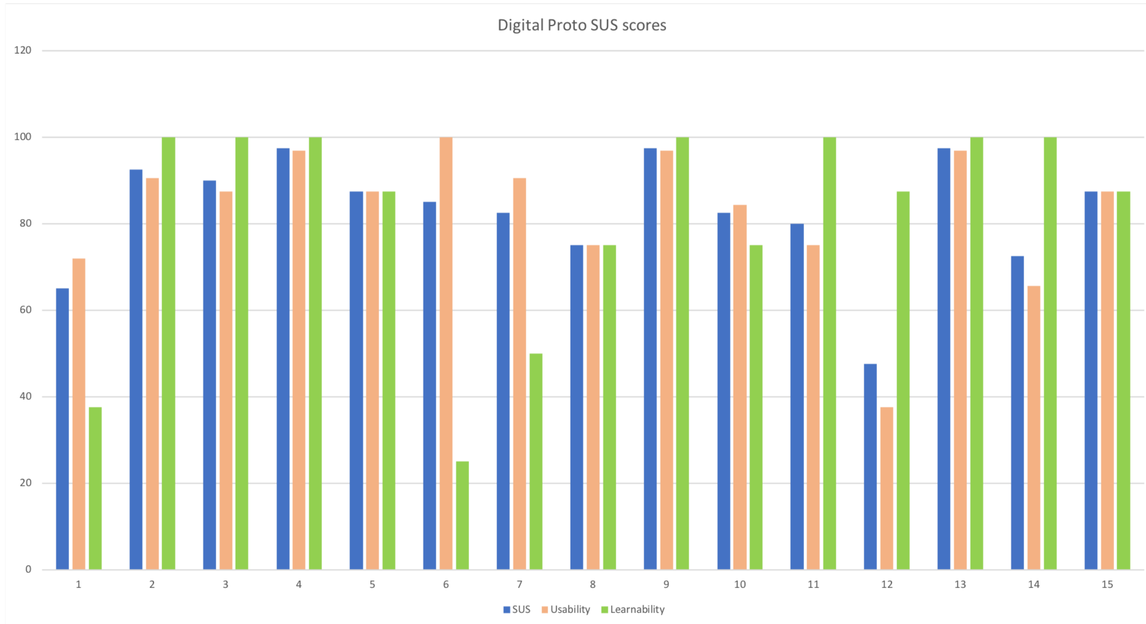


Figure 12 - Data visualization of SUS for central prototype

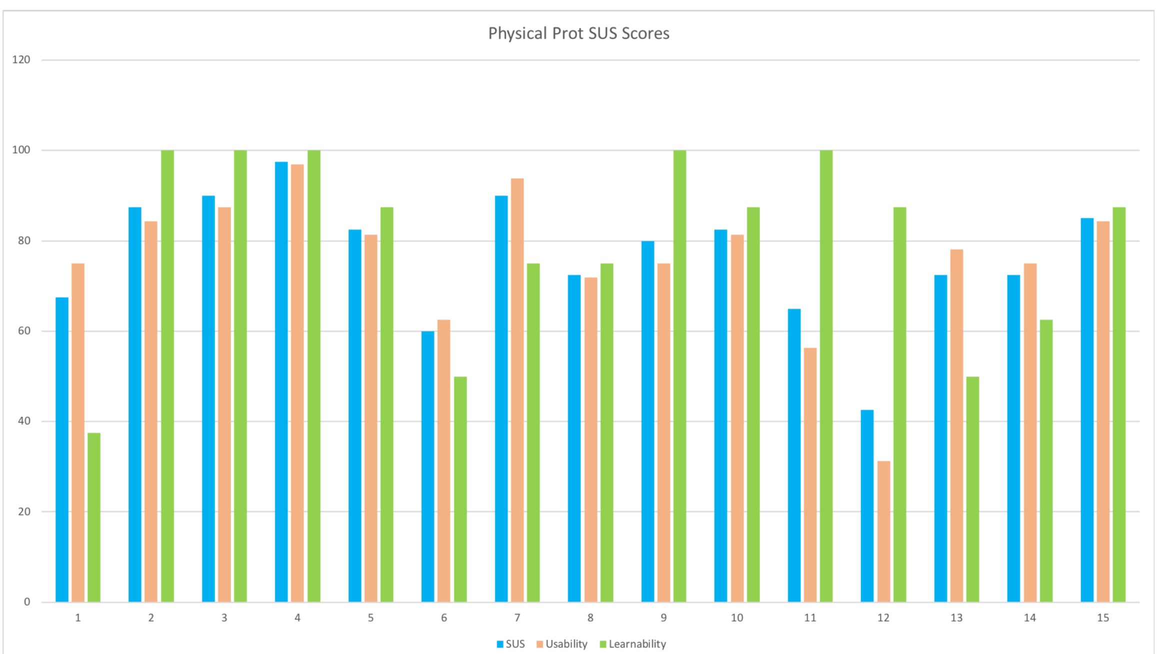


Figure 13 - Data visualization for SUS scores for peripheral prototype

4.3.1 Central UI Prototype

The central UI prototype received an average *SUS Score:* 82.7, *Learnability*: 81, *Usability:* 82.9, *Standard Deviation:* 13.6, and *Cronbach's alpha:* 0.784. In SUS terms this would be considered a high score. 14 out of 15 participants found the digital interface easy to understand and use as it was presented on a platform (iOS) that users were already familiar with. One participant reported that they would have understood and reacted to the interface without researchers having to prime them before the study started. 12 out of 15 participants reported that they preferred the central interface because it required fewer steps than the peripheral interface to engage the Point of Interest and hence, they felt their reactions were faster. Participants appreciated the interface interrupting their active task to inform them of the POI. However, although 10 out of 15 participants tested preferred the central prototype over the other two, some concerns were raised about the interface itself. For example, two participants highlighted that they would only want to be interrupted if it were an emergency. It reflected the same user expectation in initial design workshop.

Three participants voiced the fact that the reference ring surrounding the arrow of the central interface was not very helpful. Two participants complained about the animation the alert performed being too slow. Specifically, one participant mentioned that when the screen would go blank, they could not tell whether they were receiving an alert or another interruptive system event like a regular phone call. Some participants also indicated that the distance information provided by the central prototype was insufficient as they did not bother with reading text on screen.

4.3.2 Peripheral UI Prototype

The peripheral prototype received an average *SUS Score:* 76.5, *Learnability:* 80 3. *Usability:* 75.6, *Standard Deviation:* 14.6, and *Cronbach's alpha:* 0.78. In SUS terms this would be considered slightly above average, however, it is important to note this study deployed a small sample size. Similar to the central prototype, participants highlighted that the peripheral prototype was easy to understand once researchers demonstrated its functionality during the demo session. However, the peripheral UI received more controversial feedback compared with the central one. For example, three participants appreciated the fact that the prototype allowed them to continue participating in the secondary task without interruption. One, however, disagreed and voiced his frustration over having to look up knowing that he was losing his game. Six participants felt they engaged the peripheral alert at a faster rate due to audio and mechanical feedback received by the turning of the servo motors. This meant they were aware of the peripheral prototype by other sensory channels before noticing it visually. Meanwhile, the physical materiality lead to participants voicing their concerns on implementation. The most consistent feedback related to wear and tear associated with a mechanical system similar to the peripheral prototype. Additionally, participants were concerned about breakage or device malfunction should the physical arrow hit any surface of the vehicle's HMI accidentally. As the interface was attached parallel to the back surface of the mobile device, it was not clearly visible in certain orientations. This forced some participants to have to tilt their devices to properly view the alert, causing minor frustration, which was communicated by two participants. Finally, two participants felt that the weight and the additional added aesthetic of the peripheral prototype to the mobile device was a concern from a product development standpoint.

CHAPTER 5. DISCUSSION

5.1 Directional Indicators

Upon reviewing the feedback received through user interviews and sketch suggestions, it became clear that all participants, bar one, preferred receiving directional alerts; they reported that the alerts assisted them in identifying the point of interest in a faster manner. Additionally, multiple participants reported directional indication making the task easier from a cognitive and physical standpoint. One participant's quote articulated the sentiment as follows: "I felt like I had to only worry about one side of the screen instead of looking for the POI in the entire screen". Apart from qualitative feedback, the two directional indicators were subjected to SUS evaluations. The qualitative feedback was used to understand why each prototype received their respective scores. Overall, people cited the digital prototype's compass-like design and task disruption as reasons for preferring it over the peripheral one. Additionally, participants felt it would be easier to implement a digital solution as that would only require them to "download an App" and that the solution would then be platform agnostic.

Some users did appreciate the fact that the peripheral prototype did not disturb their active task. That being said, although the prototype received lower scores, participants felt like it showed great potential. We believe another reason for lower scores for the peripheral interface would have been the reduced finesse it demonstrated in comparison to the digital interface. The aesthetic appearance may have influenced participants' opinion of the peripheral interface and how it could be implemented. As a recommendation for the next user study, it may be beneficial for researchers to use a "works like" model for the user study but present a looks-like model when asking participants for feedback on which system could be implemented in a real-world scenario. During the post study sketching exercises, participants also provided several improvements to the design. This included creating a form that was adaptive to device orientation. As such, an upgrade would reduce the effort users had to apply to locate the interface when they are engaged and using colors and animation to signify the urgency/closeness of the point of interest to the vehicle.

5.2 Duration of Immersion

We as researchers understand that the length of engagement should be longer for such a study. However, given our low fidelity simulation, we observed it to be extremely difficult to maintain immersion for participants for more than 3 minutes during any given session. Our pilot study informed us of the ideal immersion times we should keep based upon the design of our specific simulation.

We investigated the impact of immersion on user reaction to alerts by defining it as a variable directly proportional to time spent on the secondary task. Our initial hypothesis stated that the more immersed users were in a task, the slower they would be to react to an alert as they dedicate more cognitive resources towards their mobile device.

Results from the ANOVA indicated no significant differences in reaction times between the immersion conditions for both the digital and non-directional interfaces. That being said, there was a significant difference in reaction time observed for the peripheral interface. Participants were slower to callout the point of interest when subjected to the 2-minute immersion condition. This suggests that users experience difficulty noticing an alert in the periphery of their attention when they are more immersed in a given task.

5.3 Gaze Movement

For the central interface, the first update would be re-orienting the arrow to be planar to the road. This would help passengers align the arrow's perspective to their own and hence locate the POI in an easier manner. This should be easily achievable from a technical standpoint wherein the interface could use the internal gyro of the mobile device to stabilize itself. Some participants indicated that the distance information provided by the central prototype was insufficient as they did not bother with reading text on screen. Instead, we propose a system where the interface pulses different colors, indicating distance of the POI from the vehicle. This would additionally help participants anticipate the urgency of the situation and assist them in reacting accordingly. Users did highlight that instead of simply pointing in a direction, they would prefer if the interface provided some form of live feed highlighting the exact object the vehicle believes is the POI. This feature would be extremely useful for instances where multiple POIs are involved.

Similarly, an improved concept for the peripheral interface was generated. The primary feature would involve the peripheral interface using the internal gyro of phone to detect device orientation with respect to the user and adapt its form accordingly so as to become visible. Multiple users complained that they were unable to view the peripheral interface when it engaged, as it was outside their field of view. This forced them to perform an extra step where they had to tilt the screen to view where the interface was pointing. An adaptive form which engages based on phone orientation would move toward addressing this problem. Similar to the central interface, the color of the LEDs depicts the distance of the POI from the vehicle. Finally, although this study focused on visual information, it became clear that participants preferred the addition of sound and vibration as it startled them into action.

CHAPTER 6. CONCLUSION

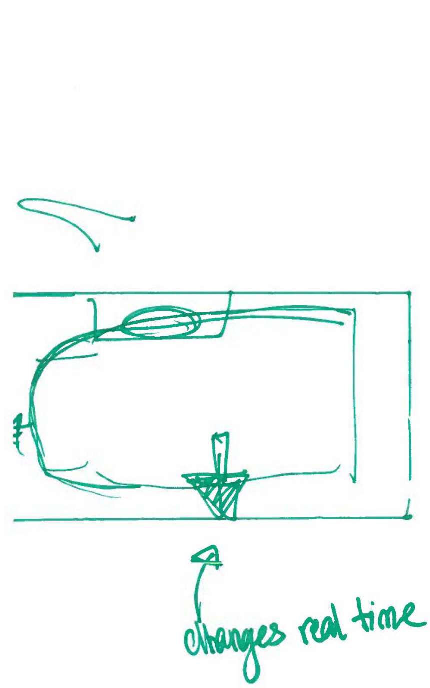
At the beginning of this research, we set out to understand whether directional indicators could assist drivers when immersed in a secondary task while riding in an autonomous vehicle. To this end we designed a user study where participants were instructed to perform a secondary task while riding in a simulated autonomous car until prompted to look up and identify a POI on the road. After reviewing reaction videos and quantitative data, it became clear that directional UI is slightly better than non-directional in reaction times to POIs. Meanwhile peripheral UI performed significantly better than the other two interfaces for short immersion conditions but faces challenges in long immersion. This would imply that the interactive system should adjust the alert method based on perceived user immersion time. Based on qualitative feedback received from most participants, it became clear that the participants generally preferred the directional alerts over the non-directional alert. This would indicate that building interfaces that can assist a user in locating the POI does lead to a more comprehensive user experience as it reduces cognitive load on participants.

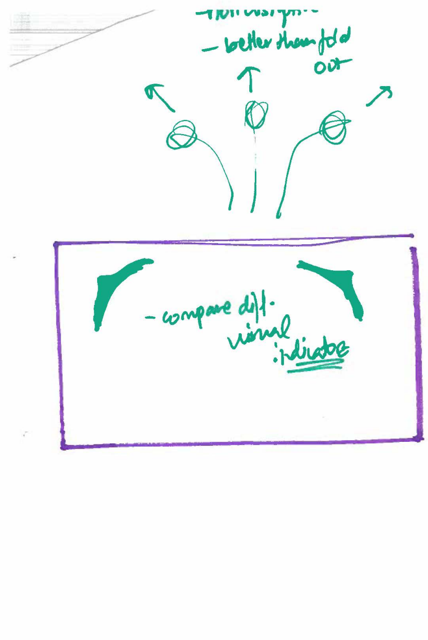
Furthermore, this user study was able to identify several behaviors that influence the manner in which a passenger may potentially react to stimuli. First and foremost, based off of our ANOVA, we observed that immersion had a direct correlation with the speed at which participants responded to external stimuli. We conclude that the more immersed a participant is in their active task, the harder it is for them to react to external stimuli in a timely manner.

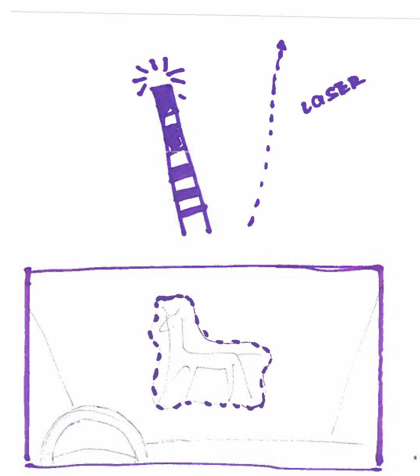
CHAPTER 7. LIMITATIONS AND FUTURE WORK

During this study, visual modalities were specifically chosen as we believed it would be hard to replicate sounds and vibrations experienced by a driver in a simulated environment. That being said, we acknowledge the differences in visual perception when seated in a controlled environment versus when in motion. The motion of the vehicle and surrounding objects could impact user reaction and perception times to external POI. Our simulator also provides a limited FOV compared to a real-world scenario, locating a POI in a 360 FOV would be more challenging than a 2D screen. For the peripheral interface, participants reported perceiving faster reactions due to the sound and vibration associated with the servo motor that was driving the peripheral interface. This was an unintentional effect of the prototype used during the user study; however, it did not seem to influence overall reaction times of participants. When asked to provide SUS scores and qualitative feedback, the functional aesthetics of the peripheral interface seemed to distract participants. This may have influenced the overall SUS scores for the peripheral interface. Finally, eye tracking data was unable to provide significant quantitative evidence regarding increase in user reaction times. This technical limitation means that further investigation using more sophisticated equipment and study design is required. In a future study, as we are testing in conditional automation conditions (level 3), we would introduce another step where users must complete a TOR after receiving alerts from our interface. We hope to understand whether improving user experience of TORs can lead to an overall improvement in driving quality post take over, an attribute of TOR that multiple studies have highlighted requires further investigation [5,7,17,20,21,25].

APPENDIX A. SKETCH DATA FROM PARTICIPATORY DESIGN WORKSHOP







APPENDIX B. SIMULATOR SETUP

The simulation setup consists of a high definition Television, steering wheel and foot pedal game controller. Participants of this simulation will be seated in a chair. The steering wheel and foot pedal are present only to serve as dummy devices to reinforce immersion of sitting inside a vehicle. Participants are not required interact with the simulation at all. During an active session, the television plays first person view footage of a car driving.

APPENDIX C. RECRUITMENT SCRIPTS

Interview:

Direct contact with potential study participants. Study team members may directly contact potential participants either in person, in the physical space of school of industrial design during work hours.

Script:

1. Introduction of Investigator or Research Assistant Excuse me. Do you have a minute? My name is Pranav Nair. I am a graduate student at Georgia Tech, and I am working on a research study with Dr. Wei Wang.

2. Make a BRIEF statement about why he/she was selected. I am approaching you because we are looking for 24 men and women between the ages of 18 and 70 with and without driving experience.

3. Immediate opportunity to opt-out I'm here to see if you are interested in hearing more about our study. Is it OK for me to continue? If individual says no, or show no interest, then say thanks but do not continue. If he/she says yes, then continue and make plans for test at a more convenient time.

4. Brief description about the research study. Participants will be seated in a low fidelity autonomous car environment in room G-54 of the J.S. Coon building. After a short introduction, the display in the front of participants will show visual simulation of a highly autonomous vehicle driving along the road. Participants will be distracted during this

simulation with a secondary task. Alerts will prompt the passenger to look up at different instances during the simulation. Participant reactions to these alerts shall be observed and recorded using video and eye tracking software. If interested, you would have to attend only one study session which would last no more than 80 minutes. You are free to leave the study session at any given point of time.

5. If you are interested in this study, please provide me with an email and phone number so that I may schedule a time and date with you for participation.

Social Media (Facebook, Twitter, Instagram)

Hi Guys! My name is Pranav Nair, I am a Master's Student at Georgia Institute of Technology currently working on a research study with Dr. Wei Wang. The purpose of this research is to test and evaluate interaction prototypes that could possibly assist or augment the ability of the primary occupant to regain situation awareness in autonomous vehicles. We will use participatory observation and quantitative data collection in the following research. We are looking for 24 men and women between the ages of 18 and 70 with and without driving experience.

The study shall be conducted in a low fidelity simulated environment. Participants will be seated in a low fidelity autonomous car environment in room G-54 of the J.S. Coon building. After a short introduction, the display in the front of participants will show visual simulation of a highly autonomous vehicle driving along the road. Participants will be distracted during this simulation with a secondary task. Alerts will prompt the passenger to lookup at different instances during the simulation. Participant reactions to these alerts shall be observed and recorded using video and eye tracking software.

Participation in this study is entirely voluntary, there will be no compensation provided by the research team. This study will come at no cost to you as a participant apart from your time. Findings from this study may serve as valuable guidelines for future development of self-driving car interfaces.

You would have to attend only one study session which would last no more than 80 minutes. You are free to leave the study session at any given point of time.

If interested, please contact me with your phone number and preferred email address and I shall get back to you to schedule a suitable time and date for participation.

Contact Info: M +1 (404) 314-6486, Email: pnair32@gatech.edu

Email Script:

Hi Guys! My name is Pranav Nair, I am a Master's Student at Georgia Institute of Technology currently working on a research study with Dr. Wei Wang. The purpose of this research is to test and evaluate interaction prototypes that could possibly assist or augment the ability of the primary occupant to regain situation awareness in autonomous vehicles. We will use participatory observation and quantitative data collection in the following research.

I am approaching you because we are looking for 24 men and women between the ages of 18 and 70 with and without driving experience.

The study shall be conducted in a low fidelity simulated environment. Participants will be seated in a low fidelity autonomous car environment in room G-54 of the J.S. Coon building. After a short introduction, the display in the front of participants will show visual simulation of a highly autonomous vehicle driving along the road. Participants will be distracted during this simulation with a secondary task. Alerts will prompt the passenger to lookup at different instances during the simulation. Participant reactions to these alerts shall be observed and recorded using video and eye tracking software

Participation in this study is entirely voluntary, there will be no compensation provided by the research team. This study will come a no cost to you as a participant apart from your time. Findings from this study may serve as valuable guidelines for future development of self-driving car interfaces.

If interested, please respond in the affirmative to this email with your phone number and preferred email address and I shall get back to you to schedule a suitable time and date for participation.

Have a great day,

Pranav

APPENDIX D. USER STUDY PRE-STUDY DOC

#_______________ Time __________________

Task description

Greetings,

The goal of this research is to test and evaluate interaction modalities that could possibly assist or augment the ability of the primary occupant to regain situation awareness in autonomous vehicles. We will use participatory observation and quantitative data collection in the following research. To further assist you in preparation for this user test, listed below is an outline of how the study shall be conducted and a few instructions for you to follow:

1. Please relax and be your natural status during the entire tasks. We humbly request you keep your mobile devices on silent during the testing phase. If you have any confusion or question, please feel free to speak out. The test would be paused at any time based on you preferences.

2. The study will be conducted in a simulated environment, wherein you will be taken through 6 of simulations, there shall be a two-minute break between each simulation.

3. Each simulation scenario involves you, the user, travelling in a level 5 autonomous car -- on your way from point A to point B

4. During each simulation you shall be provided with a mobile device, on which you are required to play a game. You shall perform this task throughout your journey in each simulation, unless prompted otherwise by the device.

5. You will be required to wear the Tobii Eye tracker during each simulation, as well as headphones which are connected to the mobile device. You may remove these peripherals during breaks.

6. At random points during the journey - your active screen (mobile phone) shall present you with an abstract message - at this point your phone is trying to highlight a point of interest to you in you cars external environment.

7. Your goal shall be, when prompted with the alert, to try to correctly identify the point of interest by looking at it.

8. Your gaze shall be tracked using the Tobii Eye tracker. Your reactions shall be recorded on video to document your gestures and expressions during this study.

9. At the end of the study, you shall be asked to fill a simple survey. Upon completion of which you may leave the facility.

Your participation in this study is extremely appreciated.

Pranav Nair

Graduate Student, Master of Industrial Design Georgia Institute of Technology

APPENDIX E. ADULT CONSENT FORMS

CONSENT DOCUMENT FOR ENROLLING ADULT PARTICIPANTS IN A RESEARCH STUDY

Georgia Institute of Technology

Georgia Institute of Technology

Project Title:

Evaluating Benefits of providing Situational Awareness Alerts on active screen of a rider in highly autonomous vehicles

Investigators: *Principal Investigator (Wei Wang, Ph.D.) and Research Assistant (Pranav Nair, M.I.D)*

Protocol Title: H18029

You are being asked to be a volunteer in a research study.

Purpose:

• The primary goal of this research would be to try and understand whether providing directional indications to a rider of an autonomous vehicle, on their active screen (mobile phone, tablet etc.), assists them in gaining situational awareness of a point of interest (POI) in their external environment (such as a deer) at a faster rate than traditional alerts which provide no directional indication. To this end, researchers of this study plan on enrolling 24 participants.

directional indicators: symbols or signs such as arrows, that are require the viewer to look in a certain direction.

active screen: the screen or display which is actively occupying a user's attention (e.g. cellphone, tablet etc.)

Exclusion/Inclusion Criteria:

• Participants in this study must be adults (over 18 years old) and able to comfortably read, write and speak English to participate. Those who have physical, mental or vision disabilities may not be in this study.

Procedures:

• Upon arrival, you will complete a demographic questionnaire which shall asking basic questions about age, gender, and experience with regards to research, simulations, and driving.

• The total duration of the study shall be as follows: Participants would only be required to visit the study location once. Pre-test consent form and survey: 10-15 minutes.

Warm-up practice: 5 mins

Testing time: 35 - 40 mins

Post-test survey (with SUS, TLX and drawings): 5-10 minutes

Retrospective interview (with open ended question): 5-10 minutes

The total time: 75 - 80 minutes

• Please relax and be in your natural state during the tasks. We humbly request you keep your mobile devices on silent during the testing phase. If you have any confusion or questions, please feel free to speak out. The test would be paused at any time based on your preferences.

• The study will be conducted in a simulated environment, wherein you will be taken through 6 of simulations, there shall be a two-minute break between each simulation.

• The overall duration of participation including all 6 simulations, consent form, warm up sessions, interviews and surveys shall be no longer than 80 minutes for you as a participant of this study.

• Each simulation scenario involves you, the user, travelling in a level 5 autonomous car --on your way from point A to point B

A *level 5 autonomous* car is defined by SAE (Society of Automotive Engineers) International J3016 guidelines as follows:

"the full-time performance by an automated driving system of all aspects of the dynamic driving task under all roadway and environmental conditions that can be managed by a human driver"

Dynamic driving task includes the operational (steering, braking, accelerating, monitoring the vehicle and roadway) and tactical (responding to events, determining when to change lanes, turn, use signals, etc.) aspects of the driving task, but not the strategic (determining destinations and waypoints) aspect of the driving task.

• During each simulation you shall be provided with a mobile device, on which you are required to play a game. You shall perform this task throughout your journey in each simulation, unless prompted otherwise by the device.

• You will be required to wear a Tobii Eye tracker during each simulation, as well as headphones which are connected to the mobile device. You may remove these peripherals during breaks.

• At random points during the journey - your active screen (mobile phone) shall present you with an abstract message - at this point your phone is trying to highlight a point of interest to you in your car's external environment.

• The timing of these alerts shall vary for each of the 6 simulations, ranging from 2 to 5 minutes after the start of each simulation.

• Your goal shall be, when prompted with the alert, to try to correctly identify the point of interest by looking at it.

• At the end of each simulation, you shall be provided with a mid-study survey on which you will be requested to draw and locate where you saw the point of interest on the screen. The sheet shall contain the screen of the simulator for reference.

• Your gaze shall be tracked using the Tobii Eye tracker. Your reactions shall be recorded on video to document your gestures and expressions during this study.

• At the end of the study, you shall be asked to fill out four simple surveys and participate in post-study retrospective interviews. Upon completion of which you may leave the facility.

Risks or Discomforts:

• The risks involved are no greater than performing non-neutral sitting postures in daily commuting activities, such as travelling in a vehicle, while wearing an eye tracking device with form factor similar to that of spectacles and operating a handheld mobile device. The sitting postures will not be held for more than a few minutes, so there is minimal risk of injury. Similarly, the eye tracking peripheral shall be worn for no more than a few minutes at any given time. There shall be breaks for a few minutes between each session to allow you to stand up and stretch as well as remove peripheral devices. However, these peripherals have been identified as causing strain or irritation when worn for a long period of time. The researchers will be careful to observe you and listen to any concerns while the sitting postures are performed and stop the study if something is wrong or you feel discomfort. You must notify the researcher immediately if you feel uncomfortable. Because subject's contact information is being collected, there is a risk of loss of privacy, but the researchers will take precautions to keep their information confidential.

Benefits:

• You are not likely to benefit in any way from joining this study. We hope that what we learn will someday help further research in the field of human automation interaction and the design of autonomous car interfaces.

Compensation to You:

• Participation in this study is entirely voluntary. There is no compensation for participation.

Storing and Sharing your Information:

• Your participation in this study is gratefully acknowledged. It is possible that your information/data will be enormously valuable for other research purposes. By signing below, you consent for your de-identified information/data to be stored by the researcher and to be shared with other researchers in future studies. If you agree to allow such future sharing and use, your identity will be completely separated from your information/data. Future researchers will not have a way to identify you. Any future research must be approved by an ethics committee before being undertaken.

Use of Photographs, Audio, or Video Recordings:

• The video data will be stored on encrypted digital hard drives and stored in a locked cabinet in the PI's office. This material shall only be accessible to researchers involved with this study. We shall use video data to observe your reactions when prompted by the directional indicators and report those findings without mentioning any details that may link make it easy to identify you. We will not use any photographs, recordings, or other identifiable information about you in any future presentation or publication without your consent.

Confidentiality:

• The following procedures will be followed to keep your personal information confidential in this study: Your privacy will be protected to the extent required by law. All data would be stored in the locked cabinet in PI's locked office and saved in PI's office laptop with his account. The data would be monitored every week. All raw data would not be accessed by non-authorized research personnel. All data transmission would be reported and approved by PI in advance. All data will be transferred physically in either a locked suitcase or a flash drive with encrypted zip file between study members of the research team. The file in portable storage will be deleted after transferring. Your records will be kept in locked files and unless you give specific consent otherwise, only study staff will be allowed to look at them. Your name and any other fact that might point to you will not appear when results of this study are presented or published. The Georgia Institute of Technology IRB, the Office of Human Research Protections, and/or the Food and Drug Administration may look over study records during required reviews. All materials will be destroyed 3 years after the completion of the research, which would be proposed in February 2021

Costs to You:

• There are no costs to you, other than your time, for being in this study.

Conflict of Interest:

• There is not conflict of interest in this research.

Questions about the Study:

• If you have any questions about the study, you may contact Dr. Wei Wang at telephone (404) 202-9519 or wei.wang@design.gatech.edu

Questions about Your Rights as a Research Participant:

• Your participation in this study is voluntary. You do not have to be in this study if you don't want to be.

• You have the right to change your mind and leave the study at any time without giving any reason and without penalty.

• Any new information that may make you change your mind about being in this study will be given to you.

• You will be given a copy of this consent form to keep.

• You do not waive any of your legal rights by signing this consent form.

"If you have any questions about your rights as a research participant, you may contact:

Ms. Melanie Clark, Georgia Institute of Technology

Office of Research Integrity Assurance, at (404) 894-6942."

[or]

"Ms. Kelly Winn, Georgia Institute of Technology

Office of Research Integrity Assurance, at (404) 385- 2175."

If you sign below, it means that you have read (or have had read to you) the information given in this consent form, and you would like to be a volunteer in this study.

____

Participant Name (printed)

____

Participant SignatureDateTime

____

Signature of Person Obtaining ConsentDate

Consent to Store and Share your Information:

I agree that my de-identified information/data may be stored and shared for future, unspecified research.

SIGNATURE ___________________

I do not allow my de-identified information/data to be stored and shared for future, unspecified research. These may only be used for this specific study.

SIGNATURE ___________________

Page **7** of **7**

APPENDIX F. MID-STUDY SURVEY

Participants were given this sheet of paper to locate the area on the screen where they remember seeing a POI from the previous study session.

APPENDIX G. POST-STUDY SURVEY

Thank you for participating in our user study, please take a few minutes to fill out the following surveys. We would be grateful for your feedback. The first survey is NASA's TLX survey and is with reference to your experience as a participant who completed tasks in our user study today. The following two surveys are adapted from SUS (System Usability Scale) surveys to gather your feedback on the validity of our research directions.

Finally, you are presented with two sheets to sketch and comment on ways in which we can improve on both our prototypes. Instructions for the same having been provided on each sheet respectively. Thank you for your time and patience in advance.

Participant ID: _____ Site: ___________________________ Date: ___/___/___

System Usability Scale

Instructions: For each of the following statements, mark one box that best describes your reactions to the **physical** alert system *today*.

		Strongly Disagree				Strongly Agree
1.	I think that I would like to use this system frequently.	☐	☐	☐	☐	☐
2.	I found this system unnecessarily complex.	☐	☐	☐	☐	☐
3.	I thought this system was easy to use.	☐	☐	☐	☐	☐
4.	I think that I would need assistance to be able to use this system.	☐	☐	☐	☐	☐
5.	I found the various functions in this system were well integrated.	☐	☐	☐	☐	☐
6.	I thought there was too much inconsistency in this system.	☐	☐	☐	☐	☐
7.	I would imagine that most people would learn to use this system very quickly.	☐	☐	☐	☐	☐
8.	I found this system very cumbersome/awkward to use.	☐	☐	☐	☐	☐
9.	I felt very confident using this system.	☐	☐	☐	☐	☐
10.	I needed to learn a lot of things before I could get going with this system.	☐	☐	☐	☐	☐

Please provide any comments about this website:

Participant ID: _____ Site: ___________________________ Date: ___/___/___

System Usability Scale

Instructions: For each of the following statements, mark one box that best describes your reactions to the **digital** system *today*.

		Strongly Disagree				Strongly Agree
1.	I think that I would like to use this system frequently.	☐	☐	☐	☐	☐
2.	I found this system unnecessarily complex.	☐	☐	☐	☐	☐
3.	I thought this system was easy to use.	☐	☐	☐	☐	☐
4.	I think that I would need assistance to be able to use this system.	☐	☐	☐	☐	☐
5.	I found the various functions in this system were well integrated.	☐	☐	☐	☐	☐
6.	I thought there was too much inconsistency in this system.	☐	☐	☐	☐	☐
7.	I would imagine that most people would learn to use this system very quickly.	☐	☐	☐	☐	☐
8.	I found this system very cumbersome/awkward to use.	☐	☐	☐	☐	☐
9.	I felt very confident using this system.	☐	☐	☐	☐	☐
10.	I needed to learn a lot of things before I could get going with this system.	☐	☐	☐	☐	☐

Please provide any comments about this website:

NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name	Task	Date

Mental Demand — How mentally demanding was the task?

Very Low — Very High

Physical Demand — How physically demanding was the task?

Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?

Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?

Perfect — Failure

Effort — How hard did you have to work to accomplish your level of performance?

Very Low — Very High

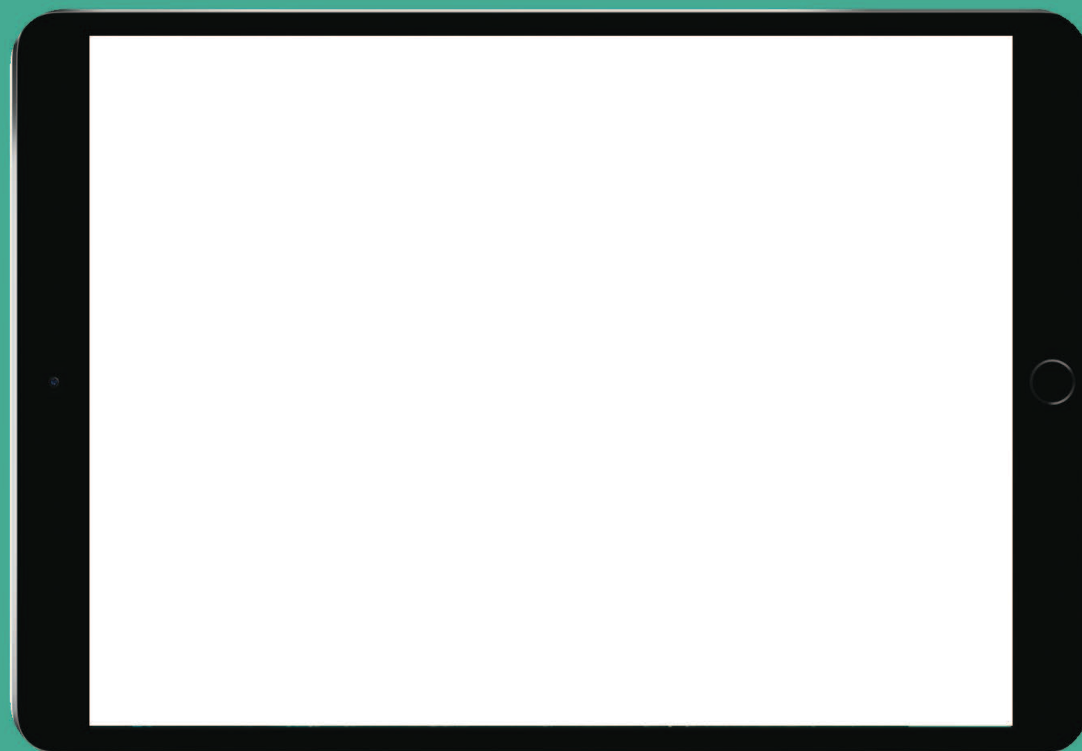
Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low — Very High


PHYSICAL INTERFACE IDEAS
Please feel free to draw out any ideas or forms you may have for improving our **physical interface prototype**. All sketches on this sheet must exist **outside** the boundaries of the iPad Pro.
Notes/Comments:

DIGITAL INTERFACE IDEAS

Please feel free to draw out any ideas or forms you may have for improving our **digital interface prototype**. All sketches on this sheet must exist **inside** the boundaries of the iPad Pro.



Notes/Comments:

APPENDIX H. POST-STUDY SURVEY

To conclude this session, please answer the following questions:

1. What were your impressions on the physical prototype?

2. What were your impressions on the digital prototype?

3. Which of the alerts did you prefer?

4. Do you have any suggestions for our user study?

Thank you for your time and patience during the course of this user study. We are extremely grateful to you for your participation.

APPENDIX I. SUS RESULTS – PERIPHERAL UI

# Participant No.	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15
Q1 - I think that I would like to use this system frequently.	3	4	5	5	3	2	4	3	3	4	1	1	3	4	4
Q2 - I found this system unnecessarily complex.	2	2	1	1	2	2	1	2	2	2	3	2	2	2	3
Q3 - I thought this system was easy to use.	5	5	5	5	5	4	5	4	4	4	4	3	5	4	5
Q4 - I think that I would need assistance to be able to use this system.	3	1	1	1	1	4	2	2	1	2	1	1	2	2	2
Q5 - I found the various functions in this system were well integrated.	4	3	5	4	5	3	4	4	4	5	3	3	3	4	5
Q6 - I thought there was too much inconsistency in this system.	2	1	1	1	2	1	1	2	2	1	3	4	1	2	1
Q7 - I would imagine that most people would learn to use this system very quickly.	3	5	1	5	4	5	5	4	5	4	5	2	5	4	5
Q8 - I found this system very cumbersome/awkward to use.	1	1	1	1	1	4	1	2	2	3	3	4	3	2	2
Q9 - I felt very confident using this system.	4	4	5	5	4	3	5	4	4	5	4	1	5	4	4
Q10 - I needed to learn a lot of things before I could get going with this system.	4	1	1	1	2	2	2	2	1	1	1	2	4	3	1
SUS	67.5	87.5	90	97.5	82.5	60	90	72.5	80	82.5	65	42.5	72.5	72.5	85
Usability	75	84.4	87.5	96.9	81.3	62.5	93.8	71.9	75	81.3	56.3	31.3	78.1	75	84.4
Learnability	37.5	100	100	100	87.5	50	75	75	100	87.5	100	87.5	50	62.5	87.5
AVERAGE SUS Score	76.5	Percentile	79	Grade	C										
AVERAGE Learnability	80														
AVERAGE Usability	75.6														
Standard deviation	14.1														
Cronbach's alpha	0.78														

APPENDIX J. SUS RESULTS – CENTRAL UI

# Participant No.	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15
Q1 - I think that I would like to use this system frequently.	4	4	4	4	4	5	4	4	5	4	2	2	5	2	4
Q2 - I found this system unnecessarily complex.	1	1	3	1	1	1	1	2	1	2	2	1	1	2	1
Q3 - I thought this system was easy to use.	3	5	5	5	5	5	5	4	5	5	4	3	4	4	5
Q4 - I think that I would need assistance to be able to use this system.	3	1	1	1	1	4	4	2	1	2	1	2	1	1	2
Q5 - I found the various functions in this system were well integrated.	4	4	5	5	4	5	4	4	4	5	4	3	5	3	5
Q6 - I thought there was too much inconsistency in this system.	3	1	1	1	2	1	1	2	1	1	2	3	1	2	1
Q7 - I would imagine that most people would learn to use this system very quickly.	4	4	4	5	4	5	5	4	5	4	5	2	5	5	5
Q8 - I found this system very cumbersome/awkward to use.	1	1	1	1	1	1	1	2	1	2	1	5	1	2	1
Q9 - I felt very confident using this system.	3	5	5	5	5	5	4	4	5	4	4	1	5	3	2
Q10 - I needed to learn a lot of things before I could get going with this system.	4	1	1	1	2	4	2	2	1	2	1	1	1	1	1
SUS	65	92.5	90	97.5	87.5	85	82.5	75	97.5	82.5	80	47.5	97.5	72.5	87.5
Usability	71.9	90.6	87.5	96.9	87.5	100	90.6	75	96.9	84.4	75	37.5	96.9	65.6	87.5
Learnability	37.5	100	100	100	87.5	25	50	75	100	75	100	87.5	100	100	87.5
AVERAGE SUS Score	82.7	Percentile	93	Grade	B-										
AVERAGE Learnability	81.7														
AVERAGE Usability	82.9														
Standard deviation	13.6														
Cronbach's alpha	0.784														

APPENDIX K. NASA TLX SCORES

Participant ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Mental Demand	50	30	70	45	85	80	25	25	45	80	20	35	20	35	25
Physical Demand	15	25	60	30	65	20	5	20	30	20	20	10	0	0	5
Temporal Demand	0	70	10	50	55	30	15	20	30	20	40	60	15	10	80
Performance	15	70	5	35	15	5	20	10	40	10	0	15	10	10	30
Effort	5	5	35	50	70	85	20	20	35	15	20	30	10	25	35
Frustration	5	20	20	20	20	65	10	10	5	15	85	0	10	15	15

Mental Demand	44.666667
Physical Demand	21.666667
Temporal Demand	33.666667
Performance	19.333333
Effort	30.666667
Frustration	21

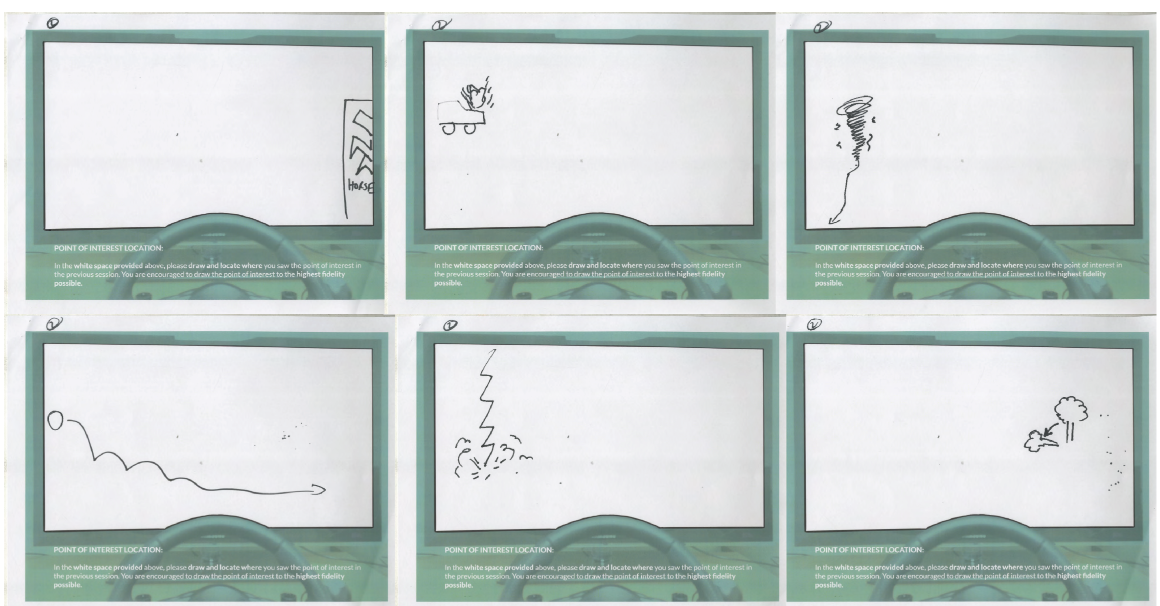
APPENDIX L. VIDEO CALLOUT DATA

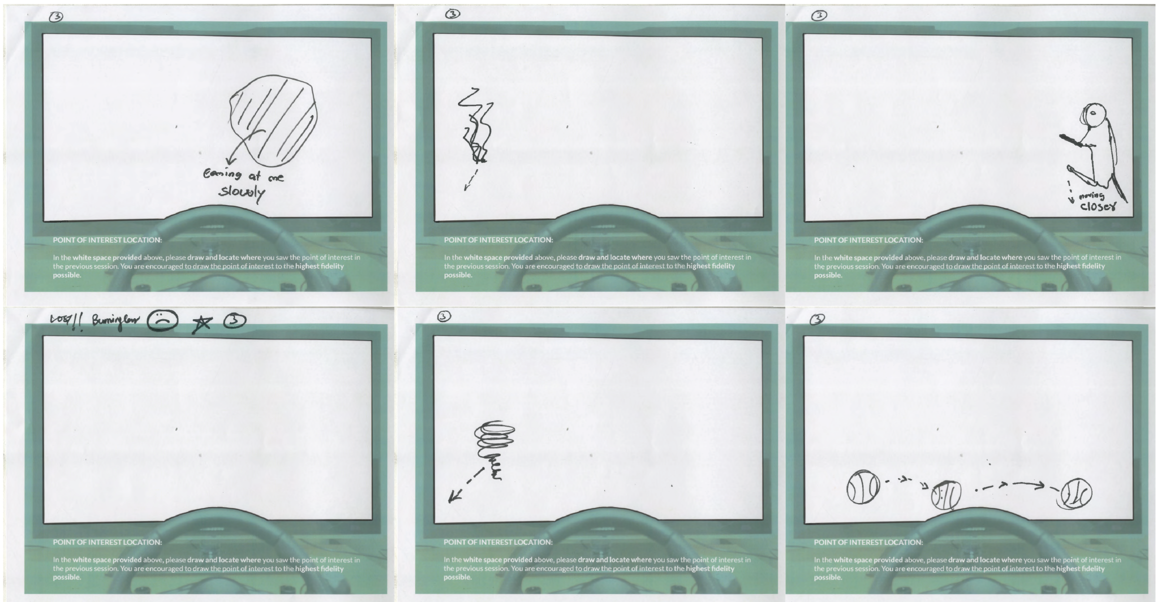
	30 sec POIs			2 min POIs					
	Digital (Tornado)	Physical (Lightning)	Traditional (Ball)	Digital (Fallen Tree)	Physical(Burning Car/Truck/Fire)	Traditional (Horse)			
1	1.8	2.2	1.2	1.4	2.4	1.4			user test error
2	1.9	1.9		2.1		2.7			missing data/not recorded
3	2.1	1.5	2.2			2			confusion
4	1.8	0.8	1.2	1.6	4	1.4			saw POI in periphery
5	2	1.2	2	2.1		2.4			alert engaged early
6	1.1	1.4	1.9	1.6	4.3	1.7			user did not call
7	1.5	1.5	1.8	1.8	2.4	1.6		0.004	error frame 2/50
8		1.4	1.2	3.1		2.5			
9*	1.7	1.9	2.1	1.7	2.8	1.8		3	neeraj burning car (2)
10	1.5	0.8	0.7	1.6	1.8	1.9		*	english not first language
11	2.9	1.3	2.1	1.8	2.9	2			
12	1.2	1.2		2.9	2.6	1.5			
13*		2	1.8	1.6		1.8			
14	2.2	1.4	1.8	2	2.1	2.5			
15	1.7	0.8	4.7	2.1	2.1	1.5			
MEAN	1.8	1.42	1.9	1.957142857	2.74	1.913333333			
STANDARD DEVIATION	0.461880215	0.437851899	0.955684746	0.495695759	0.816768701	0.430724749			

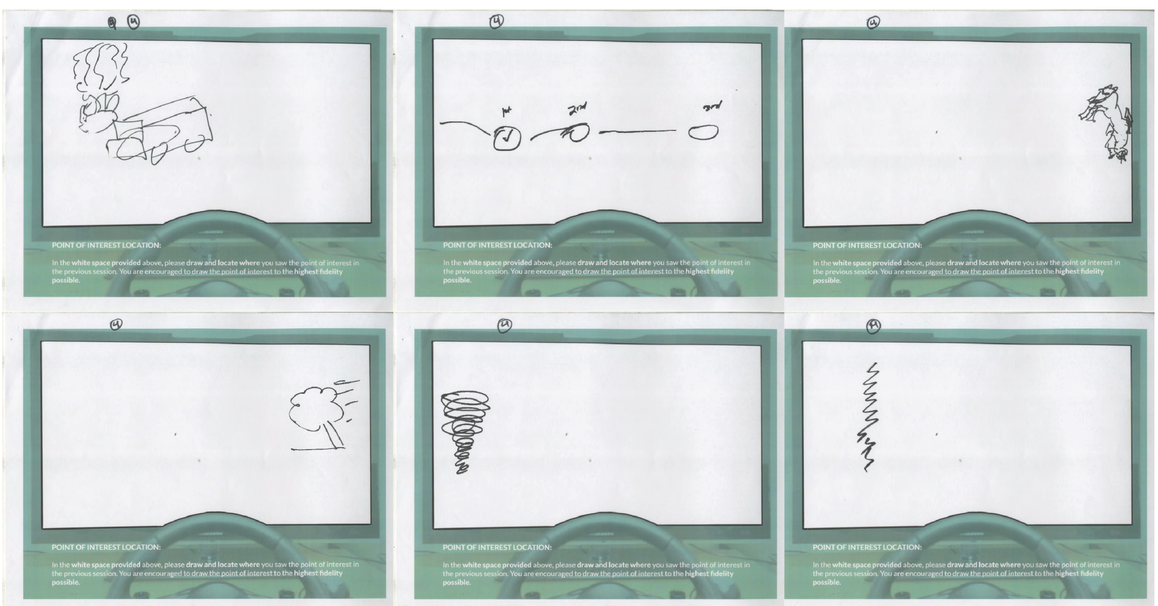
APPENDIX M. TOBII EYE TRACKER DATA

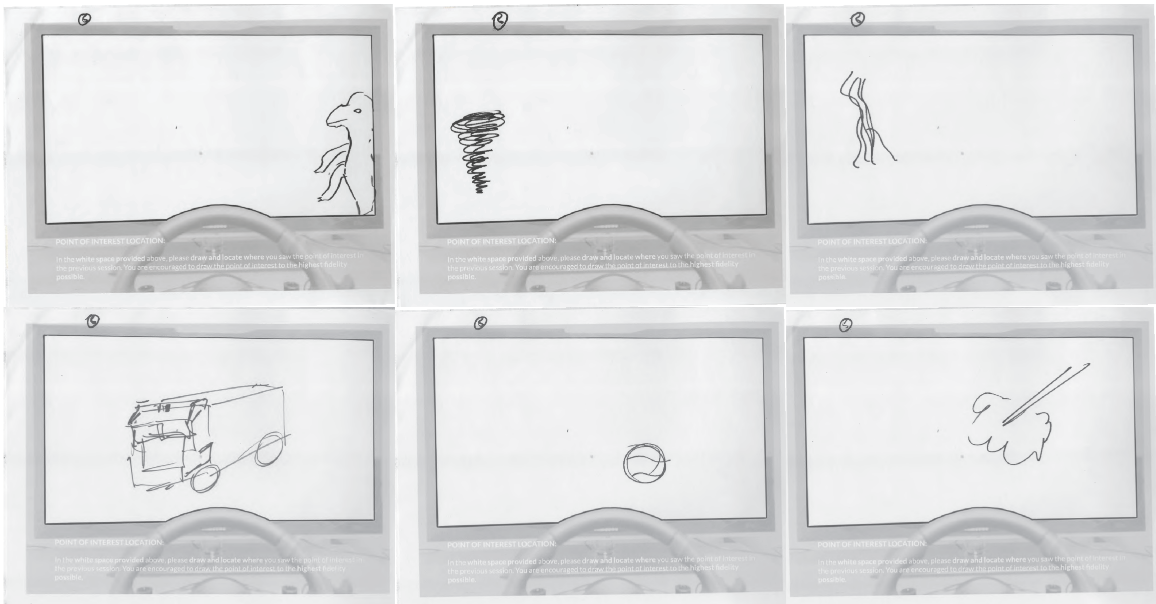
	30 sec POIs			2 min POIs				
	Digital (Tornado)	Physical (Lightning)	Traditional (Ball)	Digital (Fallen Tree)	Physical(Burning Car/Truck/Fire)	Traditional (Horse)		
1	32*	34	35*	36*	33*	37*		user test error
2	43	42	41**	39	44*	38*		missing data/not recorded
3^	45							confusion
4	49*	48*	51*	NA	47*	50*		saw POI in periphery
5	57	56	54	53*	55*%	52**		alert engaged early
6	59	62*	58*	60	63*	61		user did not call
7	68	46*	67	64	66	69	0.004	error frame 2/50
8^	70*							
9*^							3	neeraj burning car (2)
10	77**	81**	78**	80**	79*	76*	*	loss of frames
11	82	87**	86*	84	85*	83**	^	no data
12	91*	93*	89	88	92	89**	**	loss of eye track
13*^								
14	96*	94	99	98*	95	97	%	alert engaged early
15	102*	103*	100	101*	104	105		
							1 - BB	user did not notice/look at ball in first study
MEAN	59	56.5	81.8	67	89.25	0.7		
							8 - ^	had hazel eyes
STANDARD DEVIATION	14.6013698	26.60200494	20.43771024	19.8242276	16.31716887	21.2916259		

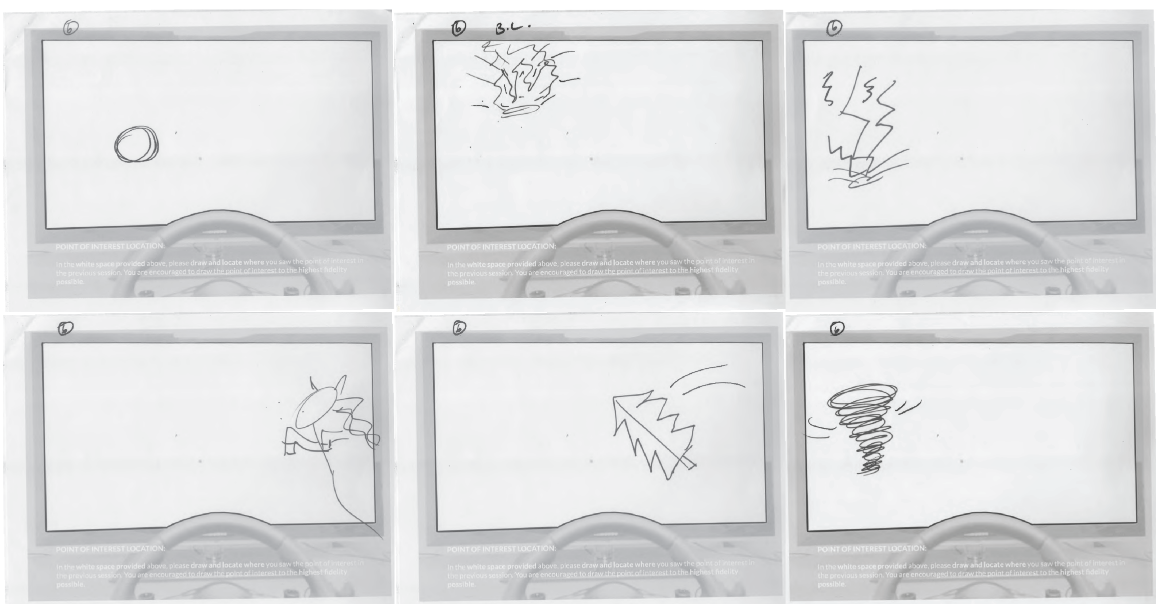
APPENDIX N. PARTICIPANT MID SURVEY POI SKETCH DATA

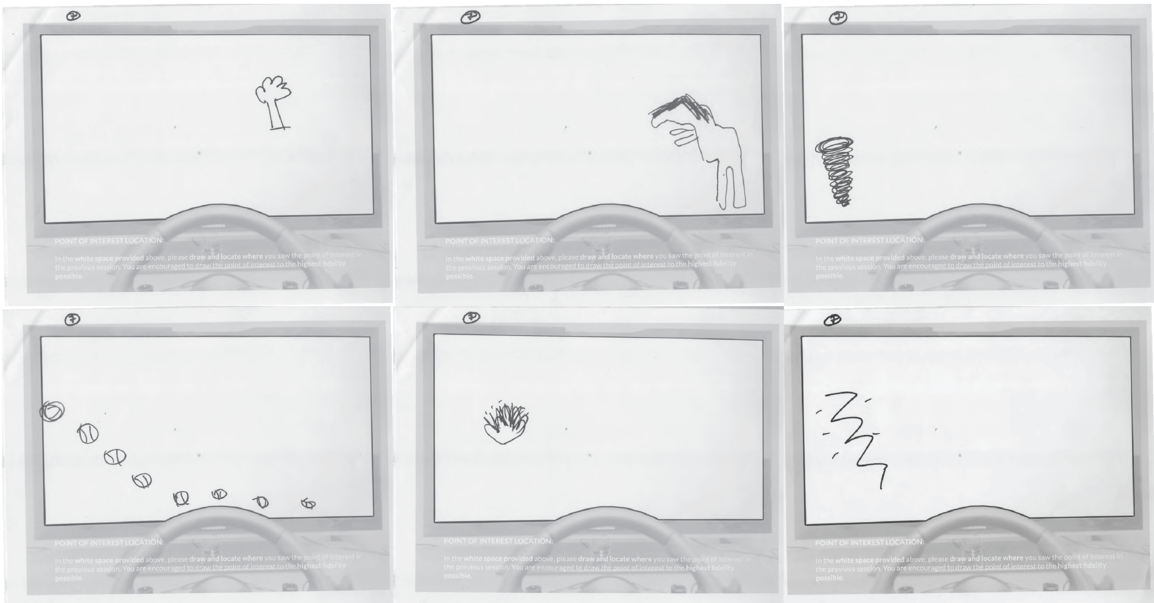


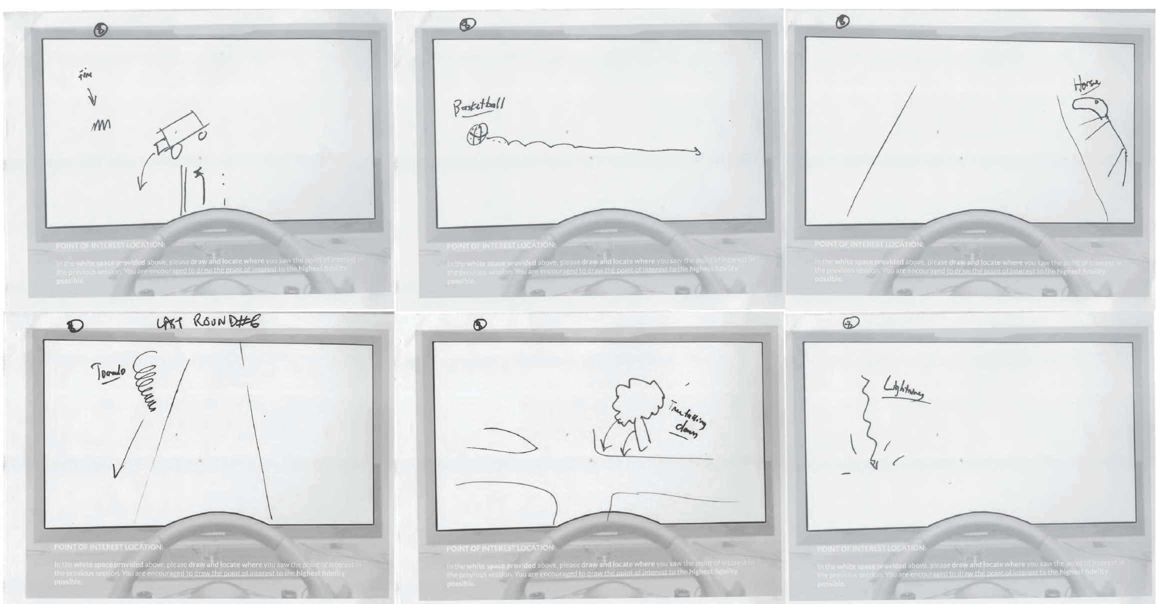

coming at me
slowly
moving
closer
POINT OF INTEREST LOCATION:
In the white space provided above, please draw and locate where you saw the point of interest in the previous session. You are encouraged to draw the point of interest to the highest fidelity possible.


POINT OF INTEREST LOCATION:
In the white space provided above, please draw and locate where you saw the point of interest in the previous session. You are encouraged to draw the point of interest to the highest fidelity possible.

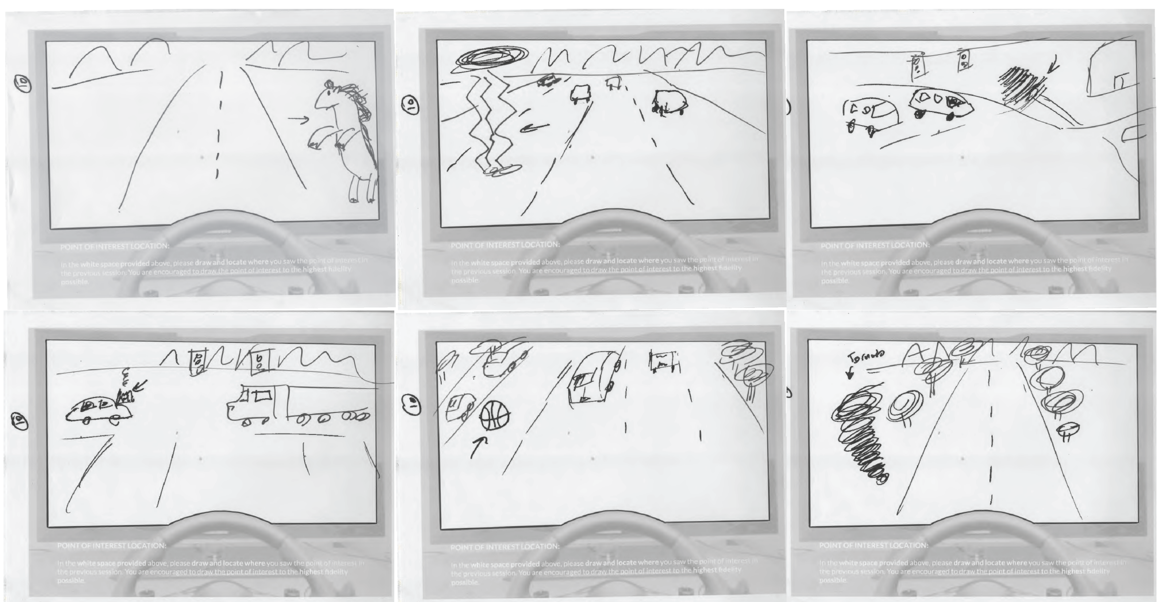

POINT OF INTEREST LOCATION:
In the white space provided above, please draw and locate where you saw the point of interest in the previous session. You are encouraged to draw the point of interest to the highest fidelity possible.

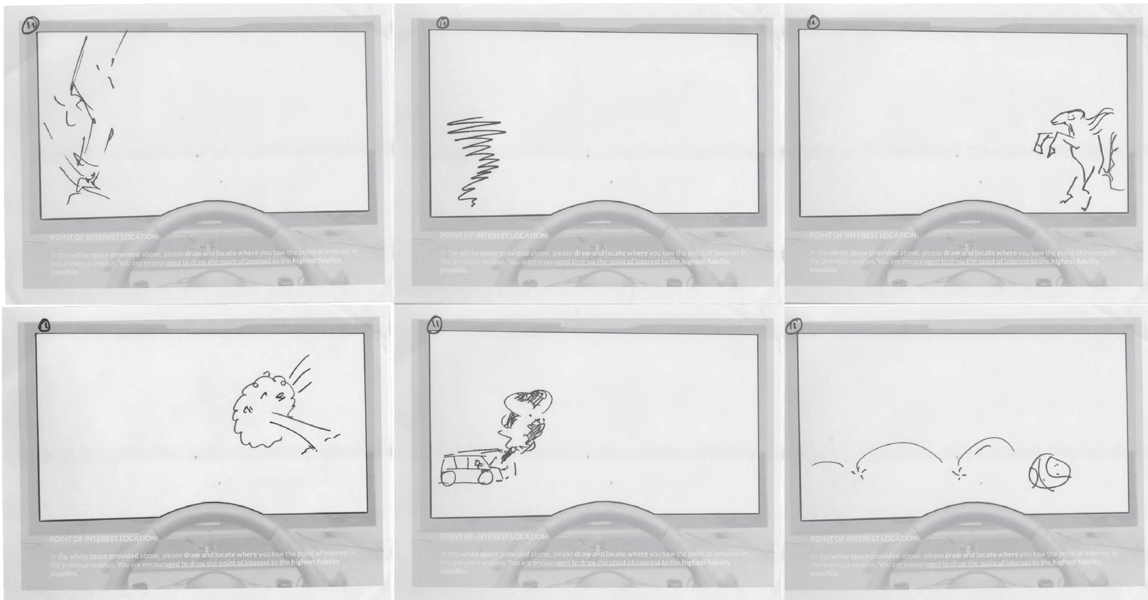

B.L.
POINT OF INTEREST LOCATION:
In the white space provided above, please draw and locate where you saw the point of interest in the previous session. You are encouraged to draw the point of interest to the highest fidelity possible.

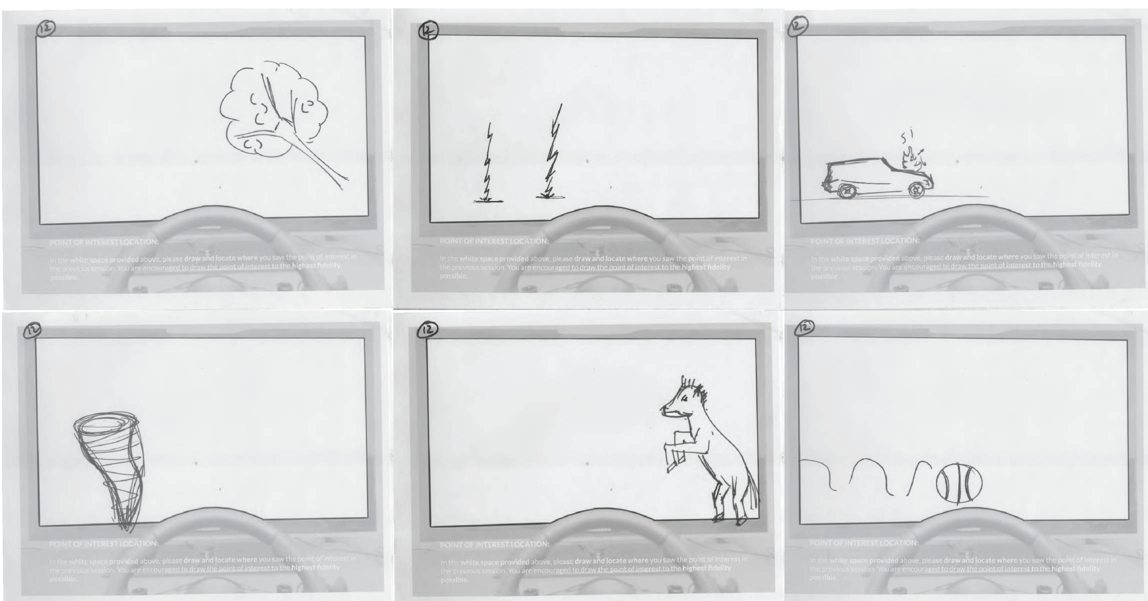


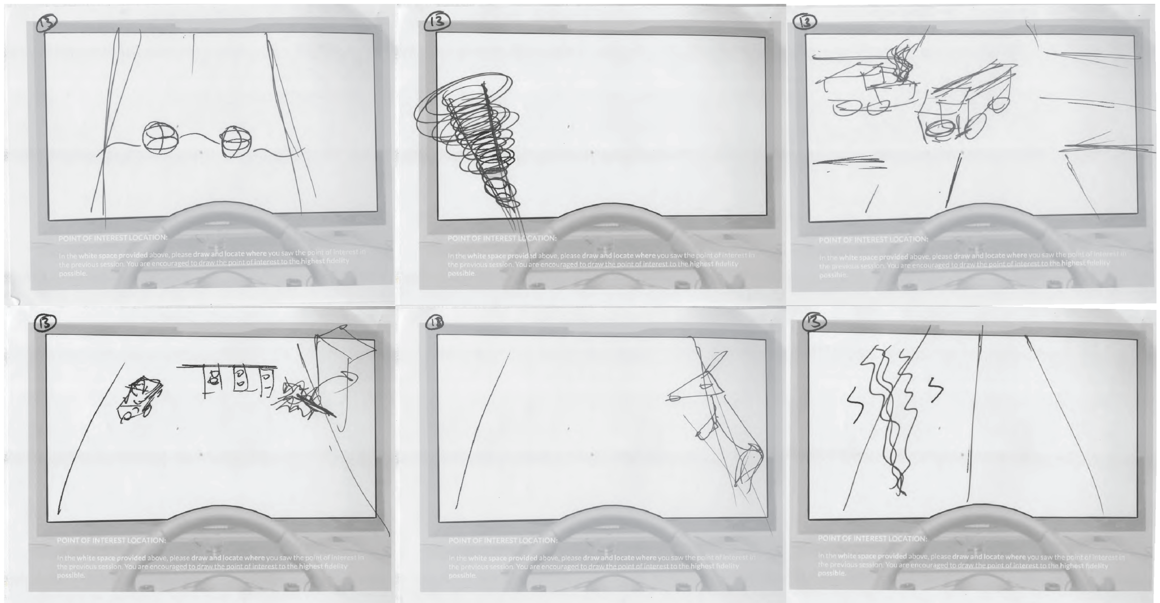

fire
Basketball
Horse

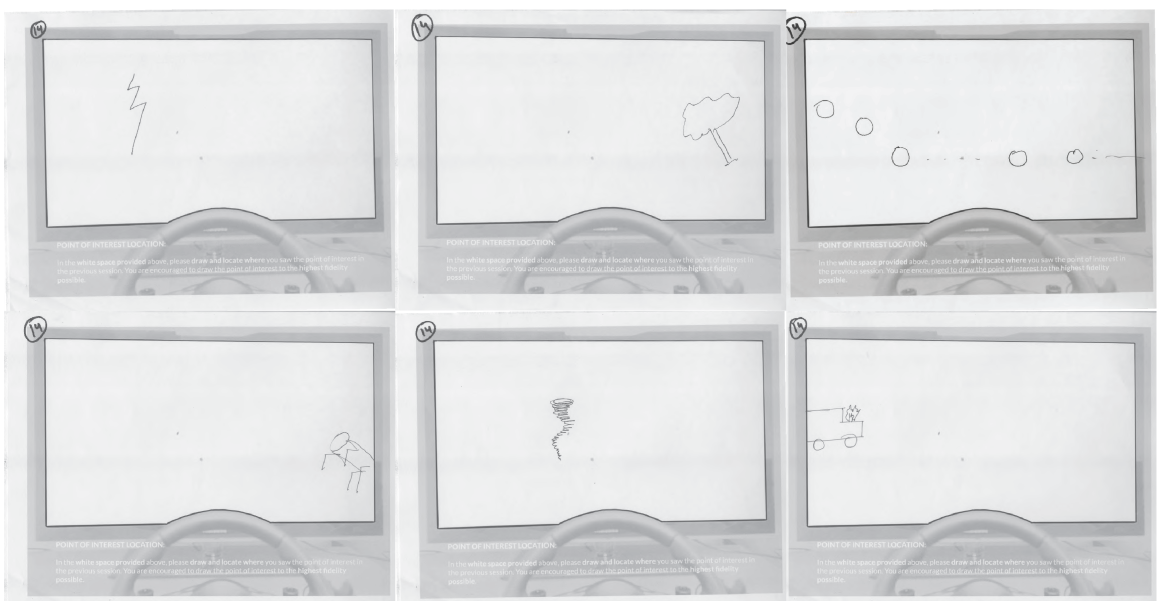

POINT OF INTEREST LOCATION:
In the white space provided above, please draw and locate where you saw the point of interest in the previous session. You are encouraged to draw the point of interest to the highest fidelity possible.

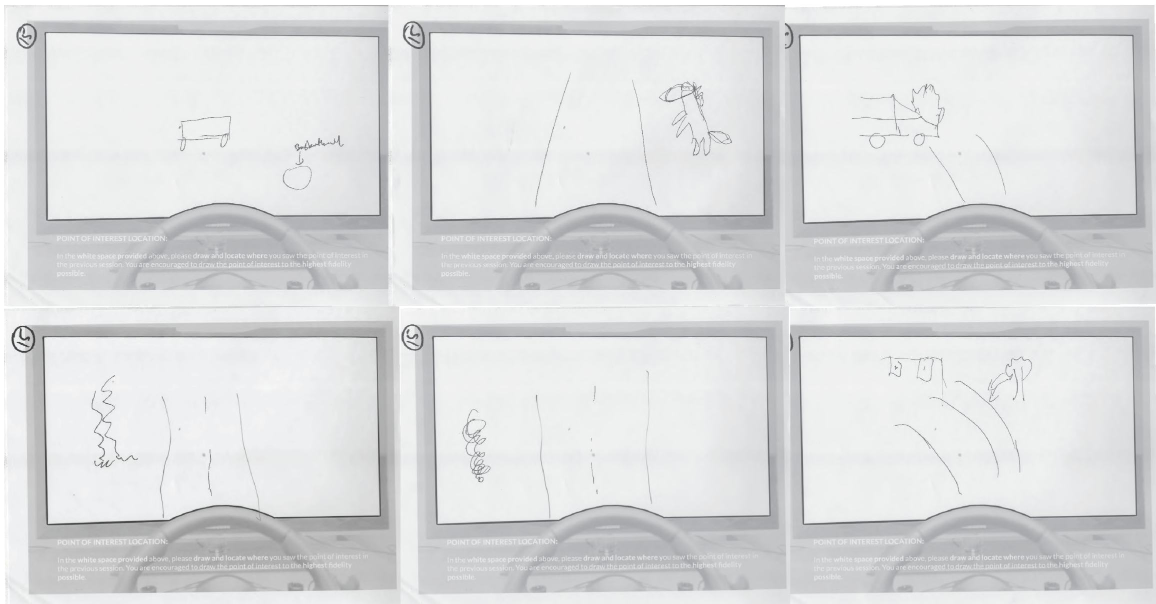

POINT OF INTEREST LOCATION:
In the white space provided above, please draw and locate where you saw the point of interest in the previous session. You are encouraged to draw the point of interest to the highest fidelity possible.
Toronto





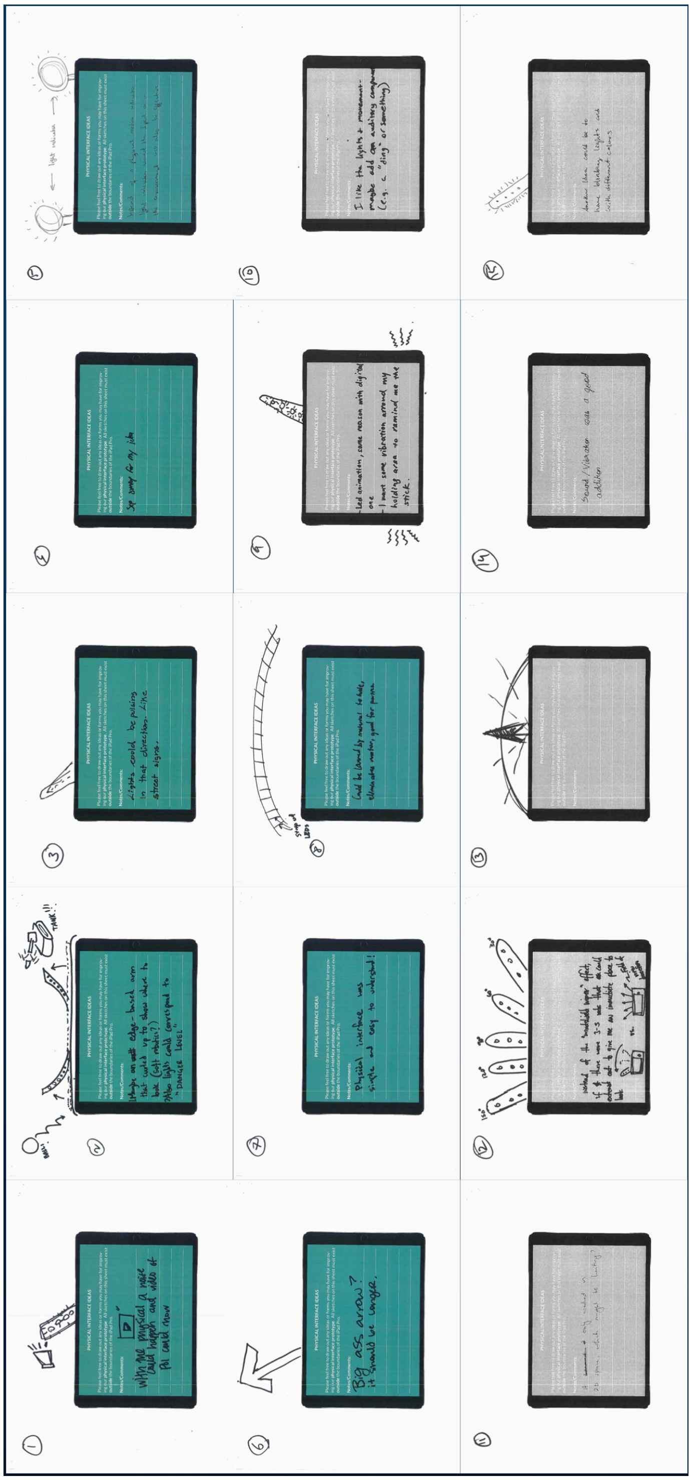

13
POINT OF INTEREST LOCATION:
In the white space provided above, please draw and locate where you saw the point of interest in the previous session. You are encouraged to draw the point of interest to the highest fidelity possible.


14
POINT OF INTEREST LOCATION:
In the white space provided above, please draw and locate where you saw the point of interest in the previous session. You are encouraged to draw the point of interest to the highest fidelity possible.

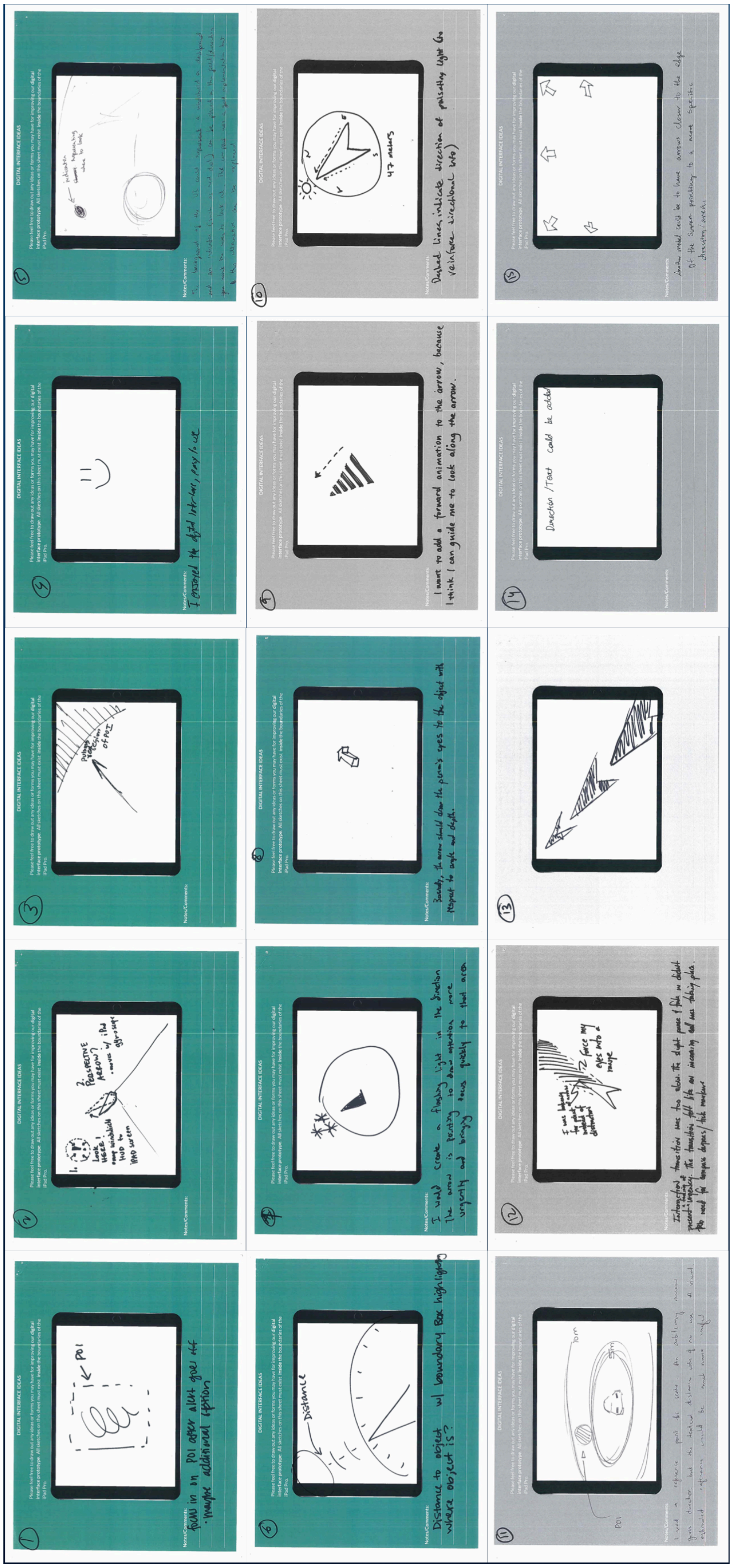

POINT OF INTEREST LOCATION:
In the white space provided above, please draw and locate where you saw the point of interest in the previous session. You are encouraged to draw the point of interest to the highest fidelity possible.

APPENDIX O. SKETCH FEEDBACK

Peripheral UI



Central UI



REFERENCES

1. Saskia Bakker. 2013. *Design for peripheral interaction*. https://doi.org/10.6100/IR754544

2. Saskia Bakker and Karin Niemantsverdriet. 2016. The interaction-attention continuum: Considering various levels of human attention in interaction design. *International Journal of Design* 10, 2: 1–14.

3. Dimitrios Gkouskos, Carl Jorgen Normark, and Sus Lundgren. 2014. What Drivers Really Want: Investigating Dimensions in Automobile User Needs. *International Journal of Design* 8, 1: 59–71.

4. Christian Gold, Daniel Damböck, Lutz Lorenz, and Klaus Bengler. 2013. "Take Over!" How Long Does It Take To Get the Driver Back Into the Loop?; "Take Over!" How Long Does It Take To Get the Driver Back Into the Loop? 1938–1943. https://doi.org/10.1177/1541931213571433

5. Christian Gold, Daniel Damböck, Lutz Lorenz, and Klaus Bengler. 2013. Take over! How long does it take to get the driver back into the loop? *Proceedings of the Human Factors and Ergonomics Society* 57, 1: 1938–1942. https://doi.org/10.1177/1541931213571433

6. Camilla Grane. 2018. Assessment selection in human-automation interaction studies: The Failure-GAM2E and review of assessment methods for highly automated driving. *Applied Ergonomics* 66: 182–192. https://doi.org/10.1016/j.apergo.2017.08.010

7. Remo M A Van Der Heiden, Shamsi T Iqbal, and Christian P Janssen. 2017. Priming Drivers before Handover in Semi-Autonomous Cars. *Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI)*: 13. https://doi.org/10.1145/3025453.3025507

8. IDEO. 2017. Future of Automobility | ideo.com. *Ideo*. Retrieved from https://www.ideo.com/post/future-of-automobility

9. InfinityWard. 2003. Call of Duty. Retrieved from https://www.callofduty.com

10. Hillary Page Ive, David Sirkin, Dave Miller, Jamy Li, and Wendy Ju. 2015. “Don’t make me turn this seat around!” Driver and Passenger Activities and Positions in Autonomous Cars. *Adjunct Proceedings of the 7th International Conference on Automotive User Interfaces and Interactive Vehicular Applications - AutomotiveUI ’15*: 50–55. https://doi.org/10.1145/2809730.2809752

11. Wendy Ju. 2015. The Design of Implicit Interactions. *Synthesis Lectures on Human-Centered Informatics* 8, 2: 1–93. https://doi.org/10.2200/S00619ED1V01Y201412HCI028

12. Eric Laurier and Tim Dant. 2012. What we do whilst driving: Towards the driverless car. In *Mobilities: New Perspectives on Transport and Society*.

13. Robert E. Llaneras, Jeremy Salinger, and Charles A. Green. 2013. Human factors issues associated with limited ability autonomous driving systems: Drivers’ allocation of visual attention to the forward roadway. *Proceedings of the Seventh International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design*: 92–98. Retrieved from http://drivingassessment.uiowa.edu/sites/default/files/DA2013/Papers/015_Llaneras_0.pdf

14. Microsoft. 2009. Mass Effect. Retrieved from https://www.masseffect.com

15. David Miller, Annabel Sun, Mishel Johns, Hillary Ive, David Sirkin, Sudipto Aich, and Wendy Ju. 2015. Distraction Becomes Engagement in Automated Driving. 2–6.

16. Brian Mok, Mishel Johns, Stephen Yang, and Wendy Ju. 2017. Reinventing the {Wheel}: {Transforming} {Steering} {Wheel} {Systems} for {Autonomous} {Vehicles}. *Proceedings of the 30th {Annual} {ACM} {Symposium} on {User} {Interface} {Software} and {Technology}*: 229–241. https://doi.org/10.1145/3126594.3126655

17. Brian Mok, Mishel Johns, Stephen Yang, and Wendy Ju. 2017. Reinventing the Wheel : Transforming Steering Wheel Systems for Autonomous Vehicles.

18. nhtsa.gov. Automated Vehicle Safety. Retrieved from https://www.nhtsa.gov/technology-innovation/automated-vehicles-safety#issue-road-self-driving

19. Hyunjoo Oh and Mark D. Gross. Paper Mech.

20. Sebastiaan Petermeijer, Pavlo Bazilinskyy, Klaus Bengler, and Joost de Winter. 2017. Take-over again: Investigating multimodal and directional TORs to get the driver back into the loop. *Applied Ergonomics* 62, February: 204–215. https://doi.org/10.1016/j.apergo.2017.02.023

21. Sebastiaan Petermeijer and Fabian Doubek. 2017. Driver response times to auditory , visual and tactile take-over requests : A simulator study with 101 participants Driver response times to auditory , visual and tactile take-over requests : A simulator study with 101 participants. April.

22. Ingrid Pettersson. 2017. Travelling from Fascination to New Meanings : Understanding User Expectations Through a Case Study of Autonomous Cars. 11, 2: 1–11.

23. Ingrid Pettersson and Wendy Ju. 2017. Design Techniques for Exploring Automotive Interaction in the Drive towards Automation. 2: 147–160.

24. Henning Pohl and Roderick Murray-Smith. 2013. Focused and Casual Interactions: Allowing Users to Vary Their Level of Engagement. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems - CHI '13*, 1: 2223–2232. https://doi.org/10.1145/2470654.2481307

25. Ioannis Politis, Stephen Brewster, and Frank Pollick. 2017. Using Multimodal Displays to Signify Critical Handovers of Control to Distracted Autonomous Car Drivers. *International Journal of Mobile Human Computer Interaction* 9, 3: 1–16. https://doi.org/10.4018/ijmhci.2017070101

26. SAE. 2016. Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles. *SAE International J3016*, 1–12. https://doi.org/10.4271/J3016_201609

27. Albrecht Schmidt and Thomas Herrmann. 2017. Intervention user interfaces. *Interactions* 24, 5: 40–45. https://doi.org/10.1145/3121357

28. Adafruit Neopixels. Retrieved from https://www.adafruit.com/category/168